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REPORT ON

INCINERATOR TECHNOLOGY EVALUATION FOR A PROPOSED HAZARDOUS WASTE FACILITY

PREPARED FOR

ONTARIO WASTE MANAGEMENT CORPORATION

Toronto, Ontario

PREPARED BY

ENGINEERING-SCIENCE
Atlanta, Georgia

NOVEMBER 1987

ENGINEERING-SCIENCE

Report On

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November 9, 1987

Ontario Waste Management Corporation
2 Bloor Street West - 11th Floor
Toronto, Ontario, Canada M4W 3E2

Attn: Mr. Edgar Schmidt, P. Eng.
Project Manager

Subject: Incinerator Technology Evaluation
ES Project No. AT111
Final Report

Gentlemen:

In accordance with our proposal dated July 15, 1987, and Mr. Schmidt's letter of July 21, 1987 authorizing us to proceed, Engineering-Science (ES) has prepared an evaluation of alternative incinerator technologies for the purpose of identifying the alternative most suited to incinerate Ontario's hazardous wastes. The evaluation has indicated that a rotary kiln incinerator with secondary combustion chamber is the preferred technology.

This is the final report giving the results and details of the work. This version incorporates the suggestions for changes and additions that have been received from Dillon, OWMC and Monenco.

We thank you for giving us the opportunity to join you in working on this important project. We will be happy to discuss the results with you at your convenience.

Sincerely,

ENGINEERING-SCIENCE, INC.

P. Rooney

Patrick Rooney, P.E.
Project Manager

PR/sls
Enclosure

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SECTION 1

INTRODUCTION AND SCOPE

1.1 INTRODUCTION

The Ontario Waste Management Corporation (OWMC) is a provincial Crown agency formally created in July 1981 by the Ontario legislature. OWMC's primary responsibility is to establish and operate a hazardous waste management facility in Ontario. As part of its work program, OWMC has identified technologies and developed general systems for the treatment and disposal of hazardous wastes. One of the generic technologies chosen was incineration for the treatment of hazardous organic wastes. Several studies performed by OWMC have indicated that a suitable incinerator equipment configuration for processing Ontario's hazardous wastes would be a rotary kiln with secondary combustion chamber. However, as part of the preparation for the forthcoming environmental assessment, OWMC has retained Engineering-Science (ES) to review and update its previous work relative to the incinerator technologies. The specific objectives of this study are:

1. Review and update previous OWMC work on incinerator technologies.
2. Identify proven incinerator technologies.
3. Choose the most suitable proven incinerator technology for treating Ontario's hazarous wastes.
4. Document the findings and present them in a report.

1.2 SCOPE

To accomplish the objectives, the following tasks were undertaken:

1. Obtain OWMC's definition of the premises and postulates which provide the framework within which the selected incinerator technologies will be expected to operate.

2. Develop an updated "long list" of incinerator technologies suited to treatment and disposal of Ontario's hazardous wastes.
3. Review previous OWMC work on incinerator technologies with particular emphasis on the 1982 Proctor & Redfern, "Generic Process Technology Studies" (Reference 4). Supplement these by literature and other references.
4. Develop factors and indicators, based on OWMC's goals, for use in evaluating incinerator technologies.
5. Identify the incinerator technologies which are proven according to OWMC's definitions.
6. Screen the factors to eliminate those factors that are not pertinent to OWMC's incinerator technology evaluation.
7. Evaluate the proven technologies.
8. Identify the preferred technology.
9. Prepare a documented report describing the work and providing conclusions identifying the incinerator technology most suitable for Ontario's hazardous wastes.

SECTION 2

INCINERATOR TECHNOLOGY EVALUATION

2.1 PREMISES AND POSTULATES*

2.1.1 Introduction

An important aspect of the evaluation and selection of appropriate components for OWMC's incineration system is to define the framework within which the selected component technologies will be expected to operate. This framework is defined by:

- o OWMC's philosophies,
- o Type and quantities of wastes which are likely to require incineration,
- o Particular treatment objectives, philosophies and assumptions (premises and postulates) which have been applied to the design of the incineration plant, and
- o Capabilities of the incineration plant in relation to those of the other major process areas (i.e., physical/chemical treatment and solidification areas) within OWMC's facility.

2.1.2 OWMC Philosophy

OWMC has developed several basic planning principles and guidelines which are central to technology selection and process design in all areas of the proposed treatment facility. The following points summarize these key treatment philosophies.

---

*Most of this section has been copied directly from Reference 1.

- OWMC's primary responsibility is to establish and operate a hazardous waste management system in Ontario. It has no responsibility for managing municipal solid waste or radioactive waste, nor is it a regulator of other industrial waste management systems (Ref: OWMC[3]).
- OWMC facilities, no matter how large or small they ultimately may be, must be designed to handle all types of special waste. This full service capability is inherent in OWMC's responsibility as a provincial crown agency.
- Wastes must undergo treatment to the fullest extent possible, using the best available proven technologies, prior to the safe disposal of the remaining treated residues.
- It is the Corporation's goal, in order of priority, to:
  - minimize risk to human health,
  - minimize environmental impacts,
  - maximize services to the hazardous waste industry,
  - minimize financial costs to OWMC and the people of Ontario.

2.1.3 Waste Profile

OWMC commissioned a waste study in Phase 1 of the Facilities Development Process which proposed a classification of Ontario special waste and estimated the types and quantities of each (Ref: OWMC[2,3,10], and Proctor & Redfern Group[4]). Additional work has subsequently been conducted to improve available data and to refine OWMC's assumptions on the quantities and characteristics of wastes it will be receiving for treatment and disposal. These most recent data have been used as a basis for ensuring that the incineration system will have the necessary processes, capacity and flexibility to respond to the waste treatment and disposal need of industries in Ontario.

Table 1 summarizes the waste classes and quantities which are likely candidates for incineration.

Conclusions drawn from the existing waste profile information have had an influence on the technology selection and process design of the incineration plant. It is recognized that the nature and quantity of the various waste types which arrive at OWMC's facility may differ from that presently envisaged and will likely continue to change

TABLE 1
CANDIDATE WASTES FOR INCINERATION

OWMC Class	Description	Typical Total Quantity Expected at OWMC Facility (t/a)	Typical Waste Quantities			
			Organics To Incineration (t/a)	Inorganics To Phys/Chem (t/a)		Inorganic Residues To Solidification (t/a)
1	Organic Waste Sludges and Still Bottoms	11,050	9,580	1,470		0
2	Solvents and Organic Solutions	3,330	3,330	0		0
3	Oil and Grease	880	880	0		0
4	Oil and Water Mixtures	3,530	3,530	0		0
5	Organic and Oily Residues	6,030	3,790	2,240		0
6	Heavy Metal Solutions and Residuals	79,480	0	66,050		13,430 (1)
7	Miscellaneous Chemicals and Products	3,100	860	2,240		0
8	Paint and Organic Residuals	5,030	4,750	280		0
9	Aqueous Solutions with Organics	1,790	600	1,190		0
10	Anion Complexes	1,070	0	1,070		0
11	Sludges and Inorganic Residuals	32,030	0	12,660		19,370 (1)
12	Pesticide and Herbicide Waste	180	180	0		0
13	PCB Wastes	30	30	0		0
14	Clean Up Residuals	2,470	2,470	0		0
	TOTALS	150,000	30,000	87,200	120,000	32,800

Notes:

1. In many instances, these are residues resulting from physical/chemical treatment at the waste generator's facility.
2. Residues from the physical/chemical treatment plant which require treatment by incineration, are omitted from the above table. These residues will be accommodated in the nominal capacity of the incineration system.
3. Waste quantities are derived from OWMC Waste Profile Information (November, 1984) and are rounded off to the nearest 10 t/a.

throughout its operating life. The ability of the selected incineration system to handle such variations was considered essential.

2.1.4 Premises

Premises are the information provided by OWMC or by other studies undertaken by the Corporation which have been taken as points of departure for new work. OWMC's basic planning principles and guidelines presented above are premises which apply to OWMC's facility as a whole including the incineration plant. The following additional premises have also been used as starting points for technology selection and process design in the incineration plant.

- The incineration plant will be designed to treat hazardous wastes which are primarily organic in nature. Wastes which are primarily inorganic in nature will be sent to the physical/chemical plant for treatment. Inorganic residues from the incineration plant will be further treated, as required, in the physical/chemical treatment and/or solidification plants prior to being disposed of in an engineered landfill. Incinerator ash may be disposed of directly in the engineered landfill unless it is shown that the leachability characteristics of this residue can be further improved by prior treatment.
- The incineration plant will be designed for an initial capacity of 30,000 t/a of organic hazardous wastes based on a total facility capacity of 150,000 t/a.
- The ultimate design capacity of the incineration plant will be 60,000 t/a, and this will be achieved by installing a second incineration system of 30,000 t/a capacity.
- Space will be provided at the facility for the installation of a second incineration system.
- The arrival of wastes at the facility will be scheduled in advance.
- The types and quantities of hazardous wastes which could require treatment at the incineration plant have been defined to the extent possible by OWMC's Waste Profile information.

- The waste profile shown in on Table 1 in the column entitled "Organics to Incineration" is typical of the types and quantities of waste the incineration plant could receive. However, variations may result from:
  - the effectiveness of 4R programs, which is to encourage industry in Ontario to reduce, recover, recycle, and reuse industrial waste,
  - industry's response to market demands and to financial constraints,
  - process and manufacturing changes, and
  - changes in provincial waste regulations.

On this basis, it is important that the incineration plant design incorporate features such as:

- maximum flexibility,
- future expansion capability, and
- reserve storage and treatment capacity.

2.1.5 Postulates

Postulates are assumptions or hypotheses which are basic to the approach used to evaluate alternatives and arrive at an optimum process design. The key assumptions, treatment objectives and treatment philosophies which have influenced technology evaluations and process design for the incineration plant are summarized below:

- The incineration plant will be designed to achieve the following treatment objectives:
  - To treat incoming hazardous waste of a primarily organic nature such as to provide a destruction and removal efficiency (DRE) of not less than 99.99% for each principal organic hazardous constituent (POHC) designated in the waste feed. This objective is consistent with the requirements of the U.S. Environmental Protection Agency (Ref: Federal Register, Vol. 47, No. 122, 24 June 1982, page 27526). While most regulating authorities have set

limits for the emission rate of organic to the atmosphere, the U.S. Environmental Protection Agency is currently the only regulating authority that attempts to regulate incinerator performance by relating the organic emission from an incinerator to the organic feed rate of the incinerator. It was decided in the early stages of conceptual design to adopt this performance requirements for OWMC's facility.

- To treat flue gases from the combustion process so that contaminants such as particulates (dust), acid gases and inorganic metals are removed to the maximum extent possible using best available proven technology, prior to the flue gases being discharged to atmosphere. The flue gas quality must ensure that the resulting point-of-impingement contaminant concentrations at least meet the requirements of the Environmental Protection Act of Ontario, RSO 1980, Regulation 308, including any provisional regulations or guidelines.
- To produce residues which can be treated by physical/chemical processes, including solidification, prior to them being safely disposed of in an engineered landfill.
- To incinerate organic residues from the physical/chemical treatment plant to the same treatment objectives established for hazardous wastes.
- To ensure that treatment objectives can be carried out safely.

o Aqueous/organic mixtures which are not amenable to physical/chemical treatment will be incinerated. Similarly, batches of inorganic waste which contain unacceptable concentrations of organics even after treatment, may also be incinerated. The incineration system will therefore be equipped to dispose of contaminated water.

- The physical form and method of delivery to the facility of organic hazardous waste, has been estimated as follows, from OWMC's waste data.

Waste Form	Method of Delivery	Tonnes/Annum (t/a)	Percentage of Organic Waste
Bulk Solids	Truck/Container	7,860	26.2
Solids and Sludges	Drums	10,200	34.0
Liquids	Drums	870	2.9
Liquids and Solids	Tank Trucks	11,070	36.9
		30,000	100.0

The incineration system must therefore be designed to accommodate varying physical forms of waste including solids, sludges, and liquids, fed to the incineration process as bulk solids, in drums or via pumps.

- Sizing of the incineration process components will be based on 7,000 operating hours a year and a capacity factor of 90 percent. Hence, the design capacity of the initial incineration system is 4.76 t/h calculated as follows:

$$\text{Design capacity} = \frac{30,000}{7,000 \times 0.9} = 4.76 \text{ t/h}$$

- The maximum continuous heat input of the incineration system will be based on waste having an average lower heating value (LHV) of 14,000 kJ/kg which has been estimated from OWMC's waste profile information. The unit will be capable of operating continuously at the resulting thermal capacity of 66.64 GJ/h.
- The incineration system must be capable of operating below its design capacity in recognition of the fact that quantities of organic waste delivered to the facility will vary, and are expected to build up over a period of years. The system will therefore be designed to operate in a safe, efficient, and reliable manner at any capacity from 50 percent to 100 percent of its rated thermal capacity.

- The incineration process will be designed to operate at temperatures of up to 1,400°C and will normally operate above 1,000°C in the primary and secondary combustion chambers prior to the introduction of secondary air. The temperature will be maintained above 1,200°C when burning certain waste types.
- The incineration system will be designed to accommodate the following variations in waste feed characteristics, based on an assessment of OWMC's waste data:

  - heating value variations from 11,000 kJ/kg to 42,000 kJ/kg without supplementary fuel firing. Below 11,000 kJ/kg supplementary fuel will be required.
  - water content varying up to 50 percent by weight of total waste feed.
  - inert solid content varying up to 30 percent by weight of total waste feed.

- The flue gas treatment system will be designed to remove particulates, heavy metals and acid gases from the flue gas produced when incinerating wastes types envisioned for OWMC's facility. The normal and maximum concentrations of chlorine and sulphur expected in the organic waste were estimated based on an assessment of OWMC's waste data, and knowledge of what similar installations were being designed for in both Europe and North America. The resultant design basis is as follows:

	% Weight	
	Normal Operation	Maximum
Chlorine	5	15
Sulphur	1	3

- The incineration plant will operate in a continuous mode, 24 hours a day, 7 days a week.
- Analytical tests will be conducted on samples of waste prior to incineration to determine important parameters such as heating value, chlorine, sulphur, water and inorganic content, and

concentrations of critical components such as certain metals. This will permit the preparation of daily "menus" of wastes to be incinerated and thereby ensure that the design limitations of the incineration system in the destruction and removal of specific chemicals, is not exceeded.

- A range of criteria were used as a basis for evaluating and comparing alternative components for the incineration system. They reflect OWMC's principal goals in minimizing risk to human health and impact on the environment.

2.2 IDENTIFICATION AND DEFINITION OF ALTERNATIVE INCINERATOR TECHNOLOGIES

The first task in the evaluation of technologies was to compile a "long list" of incinerator technologies which might be applicable to the treatment of Ontario hazardous wastes. Many incinerator technologies are available for destruction of hazardous wastes. The major subsystems that may be incorporated into a hazardous waste incineration system are:

- waste preparation and feeding,
- combustion chamber(s)
- air pollution controls
- residue/ash handling

The normal orientation of these subsystems is shown in Figure 1 along with typical process component options (Ref: Oppelt[11]). The present evaluation is concerned with the choice of the proper incinerator, i.e., combustion chambers. There are two types of combustion chamber - the primary and the secondary. They are installed in series. An incineration system usually derives its name from the type of primary combustion chamber used, e.g., fluidized bed, rotary kiln, liquid injection, pyrolytic fixed hearth.

Different incinerator technologies have been developed for handling the various types and physical forms of hazardous waste. A recent study identified 221 hazardous waste incinerators operating under the Resource

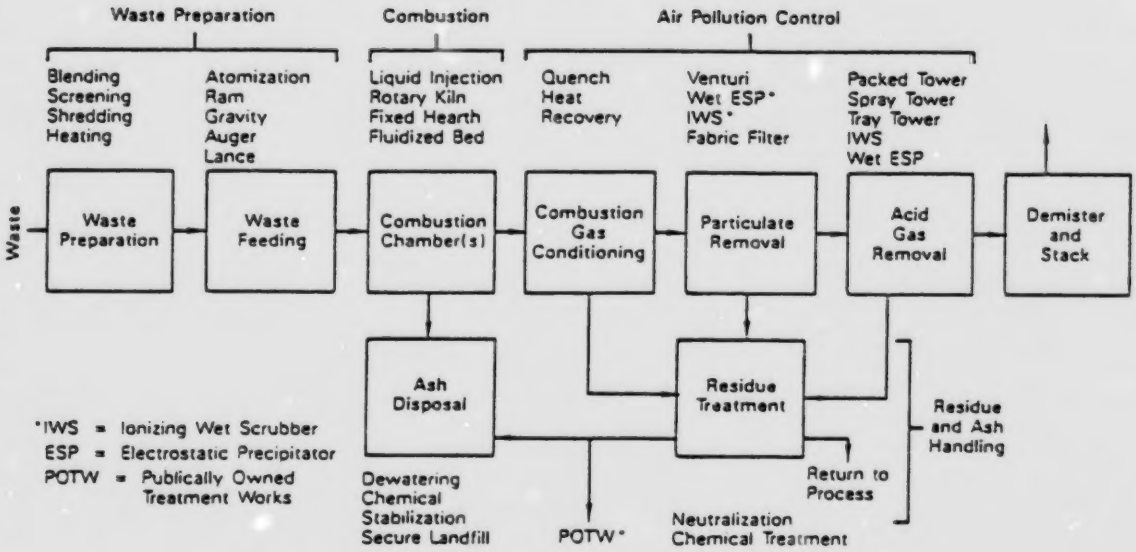

FIGURE 1. : GENERAL ORIENTATION OF INCINERATION SUBSYSTEMS AND TYPICAL PROCESS COMPONENT OPTIONS.[6]

Conservation and Recovery Act (RCRA) system in the United States[11]. Some of the results of this study were as follows:

Incinerator Design	No. of Units Reported	Average Design Capacity, MM Btu/hr
Rotary kiln	42	61
Liquid injection	95	28
Hearth	32	23
Fluidized Bed and Other	14	19

Other recent publications[12] have identified emerging incinerator technologies that offer promise as new approaches to waste treatment. These include molten salt, plasma arc/microwave plasma and rocking kiln incinerators.

Specific technologies were chosen for the long list based on information developed during earlier OWMC studies (Ref: Proctor & Redfern[4,6], A.D. Little[5], OWMC[7]), literature references, vendor contacts, and engineering judgment. The resulting compilation is a mixture of classical incineration methods and promising emerging technologies. The long list is as follows:

- Fluidized Bed
- Rotary Kiln with Secondary Combustion Chamber
- Liquid Injection
- Multiple Hearth
- Calciner/Cement Kiln
- Pyrolytic Fixed Hearth with Secondary Combustion Chamber
- Plasma Arc/Microwave Plasma
- Molten Salt Incinerator
- Rocking Kiln

A description of each of these incineration methods is given in Appendix A.

2.3 DATA COLLECTION AND ANALYSIS

This section outlines the data/sources used to identify, define and evaluate the incinerator alternatives.

The first source of data was the previous work published by OWMC on alternatives and systems including:

- Reference 4: Proctor & Redfern Group, "Generic Process Technology Studies," August, 1982
- Reference 6: Proctor & Redfern Group, "European Tour," September, 1982 (reprinted February, 1984)

These were supplemented by literature references and other information on incineration technologies compiled by Engineering-Science while preparing recent reports about incineration for various clients. ES' files are maintained up to date by regular review of key periodicals (Reference 9).

One of the key references was a recent article (Ref: Oppelt[11]) published by Mr. E. Timothy Oppelt of the U.S. Environmental Protection Agency entitled, "Incineration of Hazardous Waste: A Critical Review." In addition to containing an excellent technical review, the article lists 178 references many of which were pertinent to this evaluation.

These references were supplemented by the results of direct and/or telephone contacts with vendors of incineration equipment, primarily to obtain current information on the status of emerging technologies.

Additional technical references used are listed in the Bibliography.

2.4 IDENTIFICATION OF FACTORS

In the next step of the evaluation, the factors and indicators which would be used in making the detailed evaluation were defined.

"Factors represent positive or negative risks, impacts, costs and service considerations which would assist in comparing various sets of options. Factors are subdivided into indicators. Indicators are a way of identifying, describing and predicting risks, impacts, costs and level of service" (Reference 18). For example, two indicators for the factor entitled "risks associated with the air pathway" are quantity of effluent and emissions due to incinerator scrubber failure.

A comprehensive list of factors and indicators--entitled the "full list"--has been developed as a starting point for the evaluation process. The list is tabulated in Table 2.

TABLE 2
FULL LIST OF EVALUATION FACTORS
AND INDICATORS

RISK

Air

- o Air emissions under normal operating conditions
  - from fugitive emissions
  - from variations in amount of flue gas among technologies
- o Air emissions under abnormal operating conditions
  - from accidental releases
  - from incinerator scrubber failure
  - from variations in quality of flue gas among technologies

Surface Water

- o Surface water discharges under normal operating conditions
  - due to metal deposition in ponds and cisterns
  - from variations in amounts of flue gases among technologies
- o Surface water discharges under abnormal operating conditions
  - from accidental releases

Groundwater

- o Groundwater contamination under abnormal operating conditions
  - due to leakage of hazardous materials into groundwater
  - from accidental spills of hazardous materials

Transportation

- o Direct exposure due to accidents along access routes

Occupation Health and Safety

- o Exposure of workers during normal operations
  - from leakage from operating equipment
  - from dust generation
  - during maintenance of equipment
- o Exposure of workers during abnormal operations
  - from accidental leakage due to equipment failure or operator error
  - from gas emissions due to scrubber failure
  - from gas emissions due to excessively-rapid combustion

TABLE 2--Continued
FULL LIST OF EVALUATION FACTORS
AND INDICATORS

IMPACTS

Natural

- o Displacement of features
- o Disruption of features
- o Conflict with government policies and plans

Social

- o Displacement of residents and community features
- o Disruption of adjacent existing residents and community features
  - due to noise
  - due to visual
  - due to odors
  - due to dust
- o Disruption of adjacent future residents and community features
- o Disruption of residents and community features along access roads
- o Conflict with government policies and plans

Economic

- o Burden on municipal services and finances
- o Employment benefits

Land use

- o Compatibility with other land uses
- o Conflict with government policies and plans

Agricultural Resources

- o Displacement of resources
- o Disruption of resources

SERVICE

Resolution of Problem

- o Reliability
  - maintenance requirements
  - frequency of process upsets or breakdowns

TABLE 2--Continued
FULL LIST OF EVALUATION FACTORS
AND INDICATORS

Resolution of Problem (cont'd)

- o Flexibility
  - to variation in waste characteristics
  - to variation in waste quantities
  - speed of start-up/shutdown
- o Performance
  - destruction and removal efficiency (DRE)
  - residue characteristics
  - extent used elsewhere
- o Operations
  - complexity

COSTS

- o Approximate capital cost
- o Approximate maintenance cost

The five risk factor groupings shown in Table 2 - air, surface water, ground water, transportation and occupational health and safety - as well as the pathways - exposure resulting from normal facility operating conditions, exposure resulting from abnormal operating conditions, exposure resulting from on-site accidents and exposure resulting from transportation accidents - were based on OWMC's risk assessment mockup (Reference 18) and on Environ Corporation's generic risk assessment performed during the site selection process (Reference 15). Environ further identified the following sources of environmental releases which lead to the indicators of Table 2:

Facility Operation	Source of Release	Chemicals of Concern
A. NORMAL OPERATING CONDITIONS		
1. Waste Handling and Storage	Fugitive Emissions	Volatile organics
2. Incinerator	Stack Emissions	Organics, toxic by-products, metals and acid gases
B. ABNORMAL CONDITIONS		
1. Incinerator	Scrubber Failure	Acid gases
C. ON-SITE ACCIDENTS		
1. Waste Handling and Storage	Mixing of incompatible wastes	Hydrogen sulfide
	Tank farm fire	Volatile organics
D. OFF-SITE ACCIDENTS		
1. Transportation	Accidental spill	Volatile organics

2.5 PROVEN TECHNOLOGIES

Those factors on the list which are "exclusionary" were next identified. An exclusionary factor is one which the incinerator technology must conform to if it is to be considered further. For incineration, the exclusionary factor is "proven technology". The acceptability threshold for "proven technology" is "having been commercially demonstrated to perform reliably for a period of at least 12 months, on a scale and in a manner comparable to that required by the OWMC facility." This definition is identical with the definition stated in the OWMC's design principles and policies which in turn address these four OWMC goals, namely:

- o minimize risk to human health,
- o minimize impact on the environment,
- o maximize level of service
- o minimize cost.

The rationale is simply that a proven technology is more likely to perform as expected so that risk to human health, impact on the environment, level of service and cost can be assessed prior to selection. Performance of unproven technology with respect to these goals cannot be predicted with sufficient confidence.

The measure of this criterion is that the technology should have been demonstrated in at least one commercial application for 12 months or more at a capacity of at least 30,000 tonnes of hazardous waste feed per year or higher when feeding one or more of the wastes listed in Table 1. An incineration technology is considered unacceptable if it does not meet this measure.

It should be noted that a technology could be accepted as "proven" even if the commercial application had not included every single one of the waste feeds listed in Table 1 in order to allow for the fact that the incinerator size or materials handled which are considered comparable may vary somewhat depending on the technology.

2.6 FACTOR SCREENING

Not all of the factors in the Table 2 listing are applicable to or necessary for evaluation of incinerator technologies. Therefore, next, the full list of factors (Table 2) was screened in order to identify and eliminate those which are not applicable to this evaluation. Some were eliminated because they were not pertinent and others because they were identical for every incinerator technology. The resulting list of pertinent factors is shown in Table 3. The reasons for eliminating certain factors from this particular evaluation are enumerated in Appendix C.

2.7 EVALUATION OF TREATMENT TECHNOLOGIES

The long list of incinerator technologies listed above was screened against the exclusionary factor ("proven technology") to produce a short list of technologies.

The resulting short list of technologies is as follows:

- Fluidized Bed Incinerator
- Rotary Kiln Incinerator with Secondary Combustion Chamber (SCC)
- Liquid Injection Incinerator
- Pyrolytic Fixed Hearth with Secondary Combustion Chamber

The technologies deleted from the long list and the reasons for their deletion are tabulated in Appendix B.

Typical configurations of the four "short-list" incinerator technologies have been described in Appendix A. These can be considered as the "base cases." They are shown schematically in Figure 2. It must be recognized that these base case configurations are those used in typical industrial/commercial applications. The fluidized bed and liquid injection incinerators base case systems are capable of handling only a limited variety of hazardous waste feeds. In order for either of these two technologies to be able to process all the OWMC wastes they must be "revised" by adding additional equipment. Similarly, the pyrolytic fixed hearth base case systems must be revised to reflect the fact that two parallel trains will be needed in order to process all the

TABLE 3
PERTINENT FACTORS FOR EVALUATION OF
INCINERATOR TECHNOLOGIES

RISK

Air

- o Air emissions under abnormal operating conditions
  - from incinerator scrubber failure

Occupational Health and Safety

- o Exposure of workers during abnormal operations
  - from leakage of dust from crushing and screening equipment
  - from gas emissions due to scrubber failure
  - from gas emissions due to excessively rapid combustion

SERVICE

Resolution of Problem

- o Reliability
  - maintenance requirements
  - frequency of process upsets or breakdowns
- o Flexibility
  - to variation in waste characteristics
  - to variation in waste quantities
  - speed of start-up/shutdown
- o Performance
  - destruction and removal efficiency (DRE)
  - residue characteristics
  - extent used elsewhere

COSTS

- o Approximate capital cost
- o Approximate maintenance cost

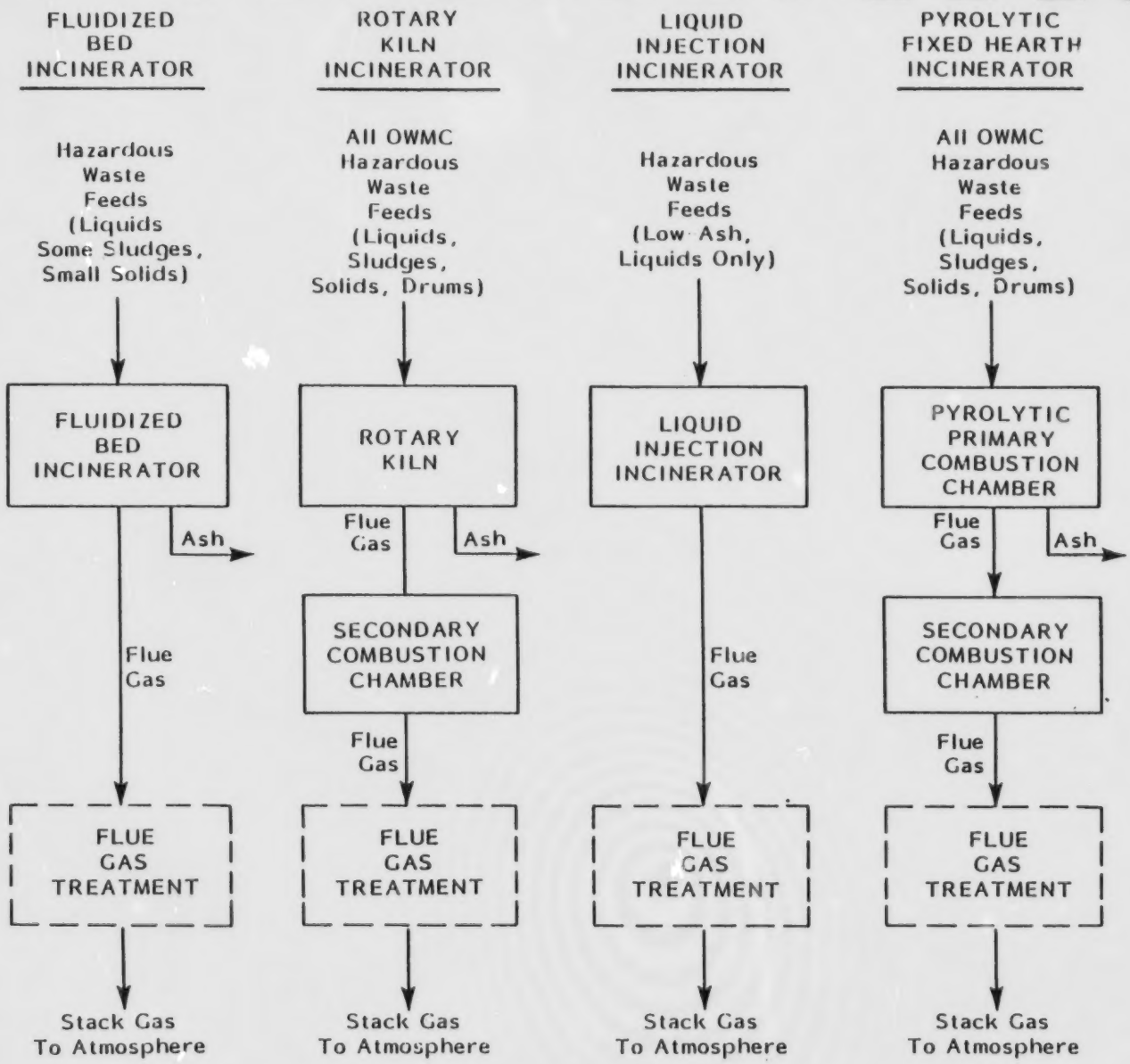

FIGURE 2. : SHORT LIST INCINERATOR TECHNOLOGIES
BASE CASE
(TYPICAL INDUSTRIAL/COMMERCIAL CONFIGURATION)

OWMC wastes. On the other hand, the rotary kiln base case system can handle all of the types of OWMC waste.

The types of revision required for the fluidized bed, liquid injection and pyrolytic fixed hearth incinerators are as follows:

1. Fluidized Bed Incinerator - Revised Case

   The typical industrial/commercial fluidized bed incinerator handles only a limited variety of liquids, sludges, and solids. The fluidized bed cannot handle solids over 51 mm in size, feeds with ash that melts below about 800°C, metallics, or high-chloride feeds. However, many of the OWMC hazardous wastes fall in the latter categories. Therefore, in order to utilize a fluidized bed incinerator for OWMC wastes, it would be necessary to install a parallel train of incinerator equipment that can handle the latter types of waste. One type of parallel equipment that experience has shown would be suitable is a rotary kiln/SCC. The use of a rotary kiln/SCC, will be assumed for the purposes of this evaluation. However, in a specific installation, other types would also be suitable and could be considered.

   In addition, the typical industrial/commercial fluidized bed incinerator handling hazardous waste feeds has not been required to meet the 99.99% destruction and removal efficiency (DRE) regulation. Therefore, in order to reduce the risk of not meeting this requirement, good engineering judgment suggests that a secondary combustion chamber should be installed with any fluidized bed installation handling OWMC wastes.

   Additionally, a fluidized bed incinerator cannot normally handle solids larger than about 51 mm size. It is anticipated that some of the OWMC solid wastes will contain larger material. However, this deficiency can be mitigated by installing crushing and screening equipment to crush the solids

to minus 51 mm. Therefore, crushing and screening equipment is included in the revised case.

A schematic diagram of the revised fluidized bed case is shown in Figure 3.

2. Liquid Injection Incinerator - Revised Case

The liquid injection incinerator is designed to handle only liquid wastes that have little or no ash (typically less than 0.5% ash). Since many of the OWMC wastes are high-ash liquids, sludges and solids, in order to utilize a liquid incinerator it would be necessary to install a parallel train of incinerator equipment that can handle the latter types of waste. One type of parallel equipment that experience has shown would be suitable is a rotary kiln. The use of a rotary kiln/SCC will be assumed for the purposes of this evaluation. However, in a specific installation, other types would also be suitable and could be considered. Similarly, for the revised case, it is assumed that the flue gases from both the liquid injection equipment and the rotary kiln/SCC can be discharged to a single train of air pollution control equipment.

3. Pyrolytic Fixed Hearth Incinerator - Revised Case

This case is revised to show two parallel fixed hearth trains for two reasons. First, the typical fixed hearth unit is not large enough to handle 30,000 tonnes per year in a single unit. Second, one of the trains would be designed to operate in batch mode in order to incinerate the wastes contained in the metal drums in the OWMC feed.

The "revised cases" are shown schematically in Figure 3. In the following evaluation, the "net effects" are for the revised cases.

As the basis for a comparative evaluation of the short list of incinerator technologies, predictions were made of effects, mitigation, and net effects for each technology against each factor or indicator which was considered pertinent (as listed in Table 3). The results of

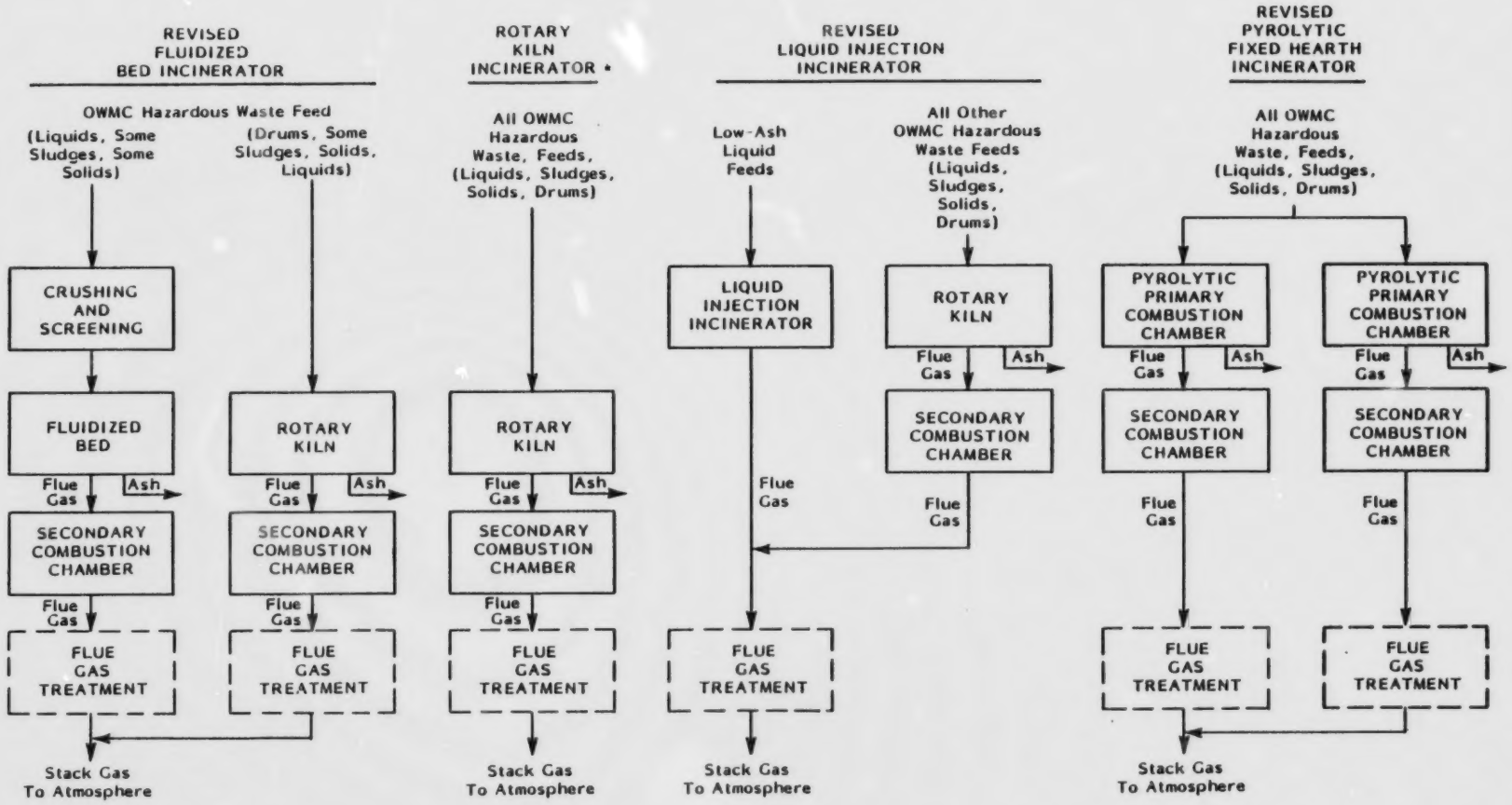
REVISED FLUIDIZED BED INCINERATOR
OWMC Hazardous Waste Feed
(Liquids, Some Sludges, Some Solids)
(Drums, Some Sludges, Solids, Liquids)
CRUSHING AND SCREENING
FLUIDIZED BED
ROTARY KILN
Flue Gas
Ash
SECONDARY COMBUSTION CHAMBER
FLUE GAS TREATMENT
Stack Gas To Atmosphere
ROTARY KILN INCINERATOR *
All OWMC Hazardous Waste, Feeds, (Liquids, Sludges, Solids, Drums)
REVISED LIQUID INJECTION INCINERATOR
Low-Ash Liquid Feeds
All Other OWMC Hazardous Waste Feeds (Liquids, Sludges, Solids, Drums)
LIQUID INJECTION INCINERATOR
REVISED PYROLYTIC FIXED HEARTH INCINERATOR
All OWMC Hazardous Waste, Feeds, (Liquids, Sludges, Solids, Drums)
PYROLYTIC PRIMARY COMBUSTION CHAMBER
* Same as Base Case

FIGURE 3. : SHORT LIST INCINERATOR TECHNOLOGIES
REVISED CASES

this comparative evaluation are given in Table 4 for the four technologies on the short list; the final column shows the "net effects" for each mitigated factor or indicator. These net effects (from Table 4) are summarized in Table 5.

The next step was to scale the net effects into three general categories: high, medium and low. "High" indicates highest risk (or least preferred) and "low" indicates lowest risk (or most preferred). The scale as applied to each effect is relative, not absolute. For example, the maintenance requirements for the rotary kiln incinerator are rated low relative to the three other alternatives because there are only two major pieces of equipment to maintain (namely, the kiln and the secondary combustion chambers), whereas the other alternatives have more major pieces of equipment. In actual fact, in absolute terms, the amount of maintenance required on any incineration process equipment is high (compared to the equipment used in low temperature processes) because of the severity of high temperature operation. The rationale for each rating is shown in Table 8. The results of the scaling of net effects are given in Table 6.

2.8 IDENTIFICATION OF PREFERRED TECHNOLOGY

The results in Table 6 were used to compare the alternative technologies, first with the high priority factors (i.e., risk factors) and then following with a comparison using secondary factors (i.e., service and cost factors). The comparison was part of the assessment used to eliminate the technologies least preferred with respect to factor ranking and magnitude of net effects. The results of the comparison of net effects is shown in Table 7.

The following assessment, based on those results, focuses on aspects which differ among the four alternative incinerator technologies considered. With respect to the following discussions it should be recalled that "low" is preferred and "high" is not preferred.

TABLE 4
COMPARATIVE EVALUATION OF INCINERATOR TECHNOLOGIES

Alternative	Effects for Factor Groupings/ Factors/Indicators	Predicted Effects	Mitigation/ Enhancement	Net Effects
Fluidized Bed Incinerator (Revised Case)	RISK			
	Air			
	o Air emissions under abnormal operating conditions - from incinerator scrubber failure	Release of sulfur dioxide, nitrogen oxides, hydrochloric acid gas, hydrofluoric acid gas from two trains of equipment (revised case) due to scrubber failure. Exposure of off-site population.	Design for automatic feed shutdown and emergency power to supply scrubber liquid in less than two minutes. Install redundant pumps and fans. Design adequate buffer zone around facility.	Expected frequency of occurrence of incinerator scrubber failure is low but double that of single incinerator train alternative.
	Occupational Health and Safety			
	o Exposure of workers during abnormal operations - from leakage of dust from crushing and screening equipment	Possibility of uncontrolled dust emissions from crushing and screening equipment; exposure of on-site personnel.	Include adequate enclosure and ventilation in design.	No dust emissions. Increased capital cost due to installation of enclosures and ventilation equipment.
	- from gas emissions due to scrubber failure	Uncontrolled release of SO_2, NO_x, HCl, HF gases from two stacks (revised case) due to scrubber failure. Exposure of on-site personnel.	Design for automatic feed shutdown and emergency power to supply scrubber liquid within two minutes. Install redundant pumps and fans. Operators use personal protective devices.	Expected frequency of occurrence low but frequency double that of alternative single incinerator train technology.
	- from gas emissions due to excessively rapid combustion	Uncontrolled release of gases to atomosphere due to combustion of waste at excessive rate. Exposure of on-site personnel.	Design adequate feed rate and temperature controls.	Very low frequency of occurrence.

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TABLE 4--Continued
COMPARATIVE EVALUATION OF INCINERATOR TECHNOLOGIES

Alternative	Effects for Factor Groupings/ Factors/Indicators	Predicted Effects	Mitigation/ Enhancement	Net Effects
Fluidized Bed Incinerator (Continued)	SERVICE			
	Resolution of Problem			
	o Reliability			
	- maintenance requirements	Two trains with six major pieces of incinerator equipment to be maintained.	Perform adequate preventive maintenance.	High maintenance requirements due to six major pieces of equipment performing under severe operating conditions.
	- frequency of process upsets or breakdowns	Six major pieces of incinerator equipment. Expected onstream time less than 80%.	Option of installing additional redundant parallel equipment to improve onstream time.	Expected onstream time less than 80% unless expensive spare equipment installed.
	o Flexibility			
	- to variation in waste characteristics	Good flexibility in design range.	None needed.	Good flexibility in design range.
	- to variation in waste quantities	Turndown capability 2:1.	None needed.	Adequate turndown capability.
	- speed of startup/shutdown	Time for cold startup varies from hours to days depending on type of refractory and operating philosophy; suitable for several hours temporary shutdown.	None needed.	Adequate speed of startup/shutdown. Continuous operation required.
	o Performance			
	- destruction and removal efficiency (DRE)	Achieves 99.99%	None needed.	Achieves 99.99%
	- residue characteristics	Residue from fluidized bed is unconsolidated ash. Residue from parallel rotary kiln is slag.	Design to solidify ash from fluidized bed prior to landfilling.	Residue is solidified ash and slag suitable for landfilling.
	- extent used elsewhere	Used widely commercially on selected waste feeds.	None needed.	Used widely commercially on selected waste feeds.
	COSTS			
	o Approximate capital cost*	$10.5 million	N/A	$10.5 million
	o Approximate maintenance cost*	$32/tonne	N/A	$32/tonne

*Incinerator only
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TABLE 4--Continued
COMPARATIVE EVALUATION OF INCINERATOR TECHNOLOGIES

Alternative	Effects for Factor Groupings/ Factors/Indicators	Predicted Effects	Mitigation/ Enhancement	Net Effects
Rotary Kiln Incinerator with Secondary Combustion Chamber	RISK			
	Air			
	o Air emissions under abnormal operating conditions			
	- from incinerator scrubber failure	Release of sulfur dioxide, nitrogen oxides, hydrochloric acid gas, hydrofluoric acid gas from one train due to scrubber failure. Exposure of off-site population.	Design for automatic feed shutdown and emergency power to supply scrubber liquid in less than two minutes. Install redundant pumps and fans. Design adequate buffer zone around facility.	Expected frequency of occurrence of incinerator scrubber failure is very low, typical of single incinerator train.
	Occupational Health and Safety			
	o Exposure of workers during abnormal operations			
	- from leakage of dust from crushing and screening equipment	No crushing and screening equipment needed.	None needed.	No dust from crushing and screening equipment. Expenditure for enclosures and ventilation equipment not needed.
	- from gas emissions due to scrubber failure	Uncontrolled release of SO_2, NO_x, HCl, HF gases from one stack due to scrubber failure. Exposure of on-site personnel.	Design of automatic feed shutdown and emergency power to supply scrubber liquid within two minutes. Install redundant pumps and fans. Operators use personal protective devices.	Frequency of occurrence very low, typical of single incinerator train.
	- from gas emissions due to excessively rapid combustion	Uncontrolled release of gases to atmosphere due to combustion of waste at excessive rate. Exposure of on-site personnel.	Design adequate feed rate and temperature controls.	Very low frequency of occurrence.
	SERVICE			
	Resolution of Problem			
	o Reliability			
	- maintenance requirements	Single train incinerator with two major pieces of equipment.	Perform adequate preventive maintenance.	Maintenance is low due to only two major pieces of equipment performing under severe operating conditions.

TABLE 4--Continued
COMPARATIVE EVALUATION OF INCINERATOR TECHNOLOGIES

Alternative	Effects for Factor Groupings/ Factors/Indicators	Predicted Effects	Mitigation/ Enhancement	Net Effects
Rotary Kiln Incinerator with Secondary Combustion Chamber (cont'd)	- frequency of process upsets or breakdowns	Two major pieces of equipment. Expected onstream time 80% to 90%.	Option of installing additional redundant parallel equipment to improve onstream time.	Expected onstream time 80% to 90% unless expensive spare equipment installed.
	o Flexibility - to variations in waste characteristics	Good flexibility in design range.	None needed.	Good flexibility in design range.
	- to variations in waste quantities	Turndown capability 2:1.	None needed.	Adequate turndown capability.
	- speed of startup/shutdown	Time for cold startup varies from hours to days depending on type of refractory and operating philosophy; suitable for several hours temporary shutdown.	None needed.	Adequate speed of startup/shutdown. Continuous operation required.
	o Performance - destruction and removal efficiency (DRE)	99.99% DRE achieved for all waste feeds.	None needed.	99.99% DRE achieved.
	- residue characteristics	Can produce difficult-to-leach slag when operated in slagging mode.	Design to operated in slagging mode.	Produce difficult-to-leach slag suitable for landfilling.
	- extent used elsewhere	Used widely commercially on multiplicity of hazardous waste feeds.	None needed.	Used widely commercially.
	COSTS			
	o Approximate capital cost*	$8 million	N/A	$8 million
	o Approximate maintenance cost*	$25/tonne	N/A	$25/tonne

*Incinerator only

TABLE 4--Continued
COMPARATIVE EVALUATION OF INCINERATOR TECHNOLOGIES

Alternative	Effects for Factor Groupings/ Factors/Indicators	Predicted Effects	Mitigation/ Enhancement	Net Effects
Liquid Injection Incinerator (Revised Case)	RISK			
	Air			
	o Air emissions under abnormal operating conditions - from incinerator scrubber failure	Release of sulfur dioxide, nitrogen oxides, hydrochloric acid gas, hydrofluoric acid gas from one train (revised case) due to scrubber failure. Exposure of off-site population.	Design for automatic feed shutdown and emergency power to supply scrubber liquid in less than two minutes. Install redundant pumps and fans. Design adequate buffer zone around facility.	Expected frequency of incinerator scrubber failure is very low, typical of single scrubber train.
	Occupational Health and Safety			
	o Exposure of workers during abnormal operations - from leakage of dust from crushing and screening equipment	No crushing and screening equipment needed.	None needed.	No dust from crushing and screening equipment. Expenditures for enclosures and ventilation equipment not needed.
	- from gas emissions due to scrubber failure	Uncontrolled release of SO_2, NO_x, HCl, HF gases from one train (revised case) due to scrubber failure. Exposure of on-site personnel.	Design of automatic feed shutoff and emergency power to supply scrubber liquid within two minutes. Install redundant pumps and fans. Operators use personal protective devices.	Expected frequency of occurrence very low, typical of single scrubber train.
	- from gas emissions due to excessively rapid combustion	Uncontrolled release of gases from incinerator to atmosphere due to combustion of waste at excessive rate. Exposure of on-site personnel.	Design adequate feed rate and temperature controls.	Very low frequency of occurrence.

TABLE 4--Continued
COMPARATIVE EVALUATION OF INCINERATOR TECHNOLOGIES

Alternative	Effects for Factor Groupings/ Factors/Indicators	Predicted Effects	Mitigation/ Enhancement	Net Effects
Liquid Injection Incinerator (cont'd)	SERVICE			
	Resolution of Problem			
	o Reliability			
	- maintenance requirements	Two-train incinerator with three major pieces of equipment.	Perform adequate preventive maintenance.	Medium maintenance requirements due to three major pieces of equipment performing under severe operating conditions.
	- frequency of process upsets or breakdowns	Three major pieces of equipment. Expected on-stream time 80% to 90%.	Option of installing additional redundant parallel equipment to improve onstream time.	Expected onstream time 80% to 90% unless expensive spare equipment installed. However, expected onstream time will be less than alternative with only two major pieces of equipment.
	o Flexibility			
	- to variations in waste characteristics	Good flexibility in design range.	None needed.	Good flexibility in design range.
	- to variations in waste quantities	Turndown capability at least 3:1.	None needed.	Good turndown capability.
	- speed of startup/shutdown	Liquid incinerator has rapid cold startup and suitable for temporary shutdown. For parallel rotary kiln, time for cold startup varies from hours to days depending on type of refractory and operating philosophy; suitable for several hours temporary shutdown.	None needed.	Adequate speed of startup/shutdown. Semi-continuous operation of liquid feed possible.
	o Performance			
	- destruction and removal removal efficiency (DRE)	99.99% achieved for all feeds (revised system).	None needed.	99.99% DRE achieved.
	- residue characteristics	No residue from liquid incinerator. Slag from parallel train.	None needed.	Revised system can produce difficult-to-leach slag suitable for landfilling.
	- extent used elsewhere	Widely used commercially on liquid feeds.	None needed.	Widely used commercially.

TABLE 4--Continued
COMPARATIVE EVALUATION OF INCINERATOR TECHNOLOGIES

Alternative	Effects for Factor Groupings/ Factors/Indicators	Predicted Effects	Mitigation/ Enhancement	Net Effects
	COSTS			
	o Approximate capital cost*	$9.2 million	N/A	$9.2 million
	o Approximate maintenance cost*	$28/tonne	N/A	$28/tonne

*Incinerator only

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TABLE 4--Continued
COMPARATIVE EVALUATION OF INCINERATOR TECHNOLOGIES

Alternative	Effects for Factor Groupings/ Factors/Indicators	Predicted Effects	Mitigation/ Enhancement	Net Effects
Pyrolytic Fixed Hearth Incinerator (Revised Case)	RISK			
	Air			
	o Air emissions during abnormal operations			
	- from incinerator scrubber failure	Release of sulfur dioxide, nitrogen oxides, hydrochloric acid gas, hydrofluoric acid gas from two trains of equipment due to scrubber failure. Exposure of off-site population.	Design for automatic feed shutdown and emergency power to supply scrubber liquid in less than two minutes. Install redundant pumps and fans. Design adequate buffer zone around facility.	Expected frequency of occurrence of incinerator scrubber failure is low but double that of single incinerator train alternative.
	Occupational Health and Safety			
	o Exposure of workers during abnormal operations			
	- from leakage of dust from crushing and screening equipment	No crushing and screening equipment needed.	None needed.	No dust from crushing and screening equipment. Expenditure for enclosures and ventilation equipment not needed.
	- from gas emissions due to scrubber failure	Uncontrolled release of SO_2, NO_x, HCl, HF gases from two trains due to scrubber failure. Exposure of on-site personnel.	Design of automatic feed shutoff and emergency power to supply scrubber liquid within two minutes. Install redundant pumps and fans. Operators use personal protective devices.	Expected frequency of occurrence low but frequency double that of single incinerator train alternative.

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TABLE 4--Continued
COMPARATIVE EVALUATION OF INCINERATOR TECHNOLOGIES

Alternative	Effects for Factor Groupings/ Factors/Indicators	Predicted Effects	Mitigation/ Enhancement	Net Effects
Pyrolytic Fixed Hearth Incinerator (cont'd)	- from gas emissions due to excessively rapid combustion	Uncontrolled release of gases from primary combustion chamber due to explosion caused by excessive in-leakage of air due to failure of feed opening controls.	Design adequate feed rate controls.	Frequency of occurrence low with proper equipment design. Risk higher than in non-pyrolytic incinerators.
	SERVICE			
	Resolution of Problem			
	o Reliability - maintenance requirements	Two trains in parallel with four major pieces of equipment.	Perform adequate preventive maintenance.	High maintenance requirements due to four major pieces of equipment performing under severe operating conditions.
	- frequency of process upsets or breakdowns	Four major pieces of equipment. Expected onstream time 80%.	Option of installing additional redundant parallel equipment to improve onstream time.	Expected onstream time 80% unless expensive spare equipment installed.
	o Flexibility - to variations in waste characteristics	Medium flexibility in design range. Solids requiring high turbulence for combustion may not be adequately treated and require re-treatment.	Option of adding parallel incinerator to treat special solids.	Medium flexibility in design range unless additional equipment installed.
	- to variations in waste quantities	Turndown capability 2:1.	None needed.	Adequate turndown capability.
	- speed of startup/shutdown	Time for cold startup varies from hours to days depending on type of refractory and operating philosophy. Slow shutdown due to solids inventory in primary chamber. Suitable for several hours temporary shutdown.	None needed.	Adequate speed of startup/shutdown. Batch operation possible for drum processing.

TABLE 4--Continued
COMPARATIVE EVALUATION OF INCINERATOR TECHNOLOGIES

Alternative	Effects for Factor Groupings/ Factors/Indicators	Predicted Effects	Mitigation/ Enhancement	Net Effects
Pyrolytic Fixed Hearth Incinerator (cont'd)	o Performance - destruction and removal efficiency (DRE)	99.99% DRE achieved for all feeds.	None needed.	99.99% DRE achieved.
	- residue characteristics	Residue can contain partially-treated waste when operated at too low temperature in primary chamber. Residue consolidated carbon-containing char.	Design adequate temperature controls. Re-treat off-specification residue.	Normally produce consolidated residue suitable for landfilling. Occasionally residue requires retreatment.
	- extent used elsewhere	Used extensively commercially in small installations.	None needed.	Used extensively commercially.
	COSTS			
	o Approximate capital cost*	$7.4 million	N/A	$7.4 million
	o Approximate maintenance cost*	$23/tonne	N/A	$23/tonne

*Incinerator only.

TABLE 5
EVALUATION OF INCINERATOR ALTERNATIVES
NET EFFECTS SUMMARY

Factor Groupings/ Factors/Indicators	Fluidized Bed (Revised Case)	Rotary Kiln	Liquid Injection (Revised Case)	Pyrolytic Fixed Hearth (Revised Case)
Risk				
Air				
o Air emissions during abnormal operations				
- from incinerator scrubber failure	Risk mitigated by equipment design and buffer zone. Expected frequency of occurrence in this two-train system is double that of expected frequency with with one-train system.	Risk mitigated by equipment design and buffer zone. Expected frequency lower with this one-train system than with two-train system.	Risk mitigated by equipment design and buffer zone. Expected frequency of occurrence lower with mitigated one-train system than with two-train system.	Risk mitigated by equipment design and buffer zone. Expected frequency of occurrence in this two-train system is double that with one-train system.
Occupational Health and Safety				
o Exposure of workers during abnormal operations				
- from leakage of dust from crushing and screening equipment.	Mitigated by installation of enclosures and ventilation. Expected frequency of dust emissions is low but higher than alternative systems.	No dust emissions. No crushing and screening equipment.	No dust emissions. No crushing and screening equipment.	No dust emissions. No crushing and screening equipment.
- from gas emissions due to scrubber failure	Risk mitigated by equipment design and buffer zone. Expected frequency of occurrence in this two-train system is very low but double that of expected frequency with one-train system.	Risk mitigated by equipment design and buffer zone. Expected frequency very low with this one-train system.	Risk mitigated by equipment design and buffer zone and by redesign to have single incinerator train. Expected frequency of occurrence in mitigated system is that of one-train system.	Risk mitigated by equipment design and buffer zone. Expected frequency of occurrence in this two-train system is double that with one-train system.
- from gas emissions due to excessively-rapid combustion.	Very low frequency of occurrence with adequate feed rate and temperature controls.	Very low frequency of occurrence with adequate feed rate and temperature controls.	Very low frequency of occurrence with adequate feed rate and temperature controls.	Risk of explosion. Expected frequency is low, but higher than other options.
Service				
Resolution of Problem				
o Reliability				
- maintenance requirements	High maintenance requirements. Six major pieces of equipment.	Low maintenance requirements. Two major pieces of equipment.	Medium maintenance requirements. Three major pieces of equipment.	Medium maintenance requirements. Four major pieces of equipment.
- frequency of process upsets or breakdown	Onstream time less than 80% when combined with rotary kiln.	Onstream time 80% to 90%.	Onstream time 80% to 90%.	Onstream time 80%.

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TABLE 5--Continued
EVALUATION OF INCINERATOR ALTERNATIVES
NET EFFECTS SUMMARY

Factor Groupings/ Factors/Indicators	Fluidized Bed (Revised Case)	Rotary Kiln	Liquid Injection (Revised Case)	Pyrolytic Fixed Hearth (Revised Case)
o Flexibility				
- to variations in waste characteristics	Good flexibility in design range.	Good flexibility in design range.	Good flexibility in design range.	Medium flexibility in design range.
- to variations in waste quantities	Adequate turndown capability, 2:1.	Adequate turndown capability, 2:1.	Good turndown capability, 3:1.	Adequate turndown capability, 2:1.
- speed of startup/ shutdown	Adequate. Continuous operation required.	Adequate. Continuous operation required.	Adequate. Continuous operation required of kiln; liquid feed may be semi-continuous.	Adequate. Batch operation possible for metal drums treatment.
o Performance				
- destruction and removal efficiency (DRE)	99.99% DRE achieved with secondary combustion chamber and combined with rotary kiln.	99.99% DRE achieved.	99.99% DRE achieved when combined with rotary kiln.	99.99% DRE achieved.
- residue characteristics	Residue from fluidized bed suitable for solidification/ landfill. Residue from kiln suitable for landfill.	Suitable for landfill.	Suitable for landfill.	Usually suitable for landfill. Periodic re-treatment required.
- extent used elsewhere	Widely used commercially.	Widely used commercially.	Widely used commercially.	Widely used commercially.
COSTS				
o Approximate capital cost*	$10.5 million	$8 million	$9.2 million	$7.4 million
o Approximate maintenance cost*	$32/tonne	$25/tonne	$28/tonne	$23/tonne

*Incinerator only

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TABLE 6
EVALUATION OF INCINERATOR ALTERNATIVES
RANKING OF ALTERNATIVES BY FACTOR

Factor Groupings/ Factors/Indicators	Fluidized Bed	Rotary Kiln	Liquid Injection	Fixed Hearth Pyrolytic
RISK				
Air				
o Air emissions during abnormal operations				
- from incinerator scrubber failure	High*	Low*	Low	High
Occupational Health and Safety				
o Exposure of workers during abnormal operations				
- from leakage of dust from crushing and screening equipment.	High	Low	Low	Low
- from gas emissions due to scrubber failure.	High	Low	Low	High
- from gas emissions due to excessively-rapid combustion.	Low	Low	Low	High
SERVICE				
Resolution of Problem				
o Reliability				
- maintenance requirements	High	Low	Medium	Medium
- frequency of process upsets or breakdowns	High	Medium	Medium	Medium

*Low = low risk = most preferred
High = high risk = least preferred

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TABLE 6--Continued
EVALUATION OF INCINERATOR ALTERNATIVES
RANKING OF ALTERNATIVES BY FACTOR

Factor Groupings/ Factors/Indicators	Fluidized Bed	Rotary Kiln	Liquid Injection	Fixed Hearth Pyrolytic
o Flexibility				
- to variations in waste characteristics	Low	Low	Low	Medium
- to variations in waste quantities	No difference among options.	No difference among options.	No difference among options.	No difference among options.
- speed of startup/ shutdown	Medium	Medium	Medium	Medium
o Performance				
- destruction and removal efficiency (DRE)	No difference among options.	No difference among options.	No difference among options.	No difference among options.
- residue characteristics	Medium	Low	Low	High
- extent used elsewhere	No difference among options.	No difference among options.	No difference among options.	No difference among options.
COSTS				
o Approximate capital cost*	High	Medium	Medium	Low
o Approximate maintenance cost*	High	Low	Medium	Low

*Incinerator only

TABLE 7
EVALUATION OF INCINERATOR ALTERNATIVES
SUMMARY OF TRADEOFFS FOR ALTERNATIVES

Factor Groupings/ Factors/Indicators	Fluidized Bed	Rotary Kiln	Liquid Injection	Fixed Hearth Pyrolytic
RISK				
Air				
o Air emissions during abnormal operations				
- from incinerator scrubber failure	Higher risk than rotary kiln option because of two-scrubber trains subject to failure.	Lowest risk option due to only one scrubber train subject to failure.	Low risk option if design includes only one scrubber train.	Higher risk than rotary kiln option because of two scrubber trains subject to failure.
Occupational Health and Safety				
o Exposure of workers during abnormal operations				
- from leakage of dust from crushing and screening equipment	Highest risk because solid feeds require crushing and screening.	Low risk option because no crushing and screening.	Low risk option because no crushing and screening.	Low risk option because no crushing and screening.
- from gas emissions due to scrubber failure	Higher risk than rotary kiln option because of two scrubber trains subject to failure.	Lowest risk option due to only one scrubber train subject to failure.	Low risk option if design includes only one scrubber train.	Higher risk than rotary kiln option because of two scrubber trains subject to failure.
- from gas emissions due to excessively-rapid combustion	Low risk option due to installation of automatic controls on feed rate and combustion.	Low risk option due to installation of automatic controls on feed rate and combustion.	Low risk option due to installation of automatic controls on feed rate and combustion.	High risk option due to primary combustion chamber operating under explosive gas conditions.
SERVICE				
Resolution of Problem				
o Reliability				
- maintenance requirements	Not preferred because of high maintenance due to complexity of six pieces of major equipment.	Preferred option because low maintenance due to only two pieces of major equipment.	Not preferred because of medium maintenance due to three pieces of major equipment.	Not preferred because of medium maintenance due to four pieces of major equipment.
- frequency of process upsets or breakdowns	Not preferred because onstream time less than 80%.	Onstream time 80% to 90%, same as liquid injection.	Onstream time 80% to 90%, same as rotary kiln.	Onstream time 80%.
o Flexibility				
- to variations in waste characteristics	Satisfactory performance. Same as rotary kiln and liquid injection.	Satisfactory performance. Same as fluidized bed and liquid injection.	Satisfactory performance. Same as fluidized bed and rotary kiln.	Not preferred because of difficulty in handling some solid wastes.

TABLE 7--Continued
EVALUATION OF INCINERATOR ALTERNATIVES
SUMMARY OF TRADEOFFS FOR ALTERNATIVES

Factor Groupings/ Factors/Indicators	Fluidized Bed	Rotary Kiln	Liquid Injection	Fixed Hearth Pyrolytic
- to variations in waste quantities	2:1 turndown adequate.	2:1 turndown adequate.	3:1 turndown adequate.	2:1 turndown adequate.
- speed of startup/ shutdown	No significant difference among options.	No significant difference among options.	No significant difference among options.	No significant difference among options.
o Performance				
- destruction and removal efficiency (DRE)	No difference among options.	No difference among options.	No difference among options.	No difference among options.
- residue characteristics	Not preferred because residue needs stabilization before landfilling.	Prefarred because residue ready for landfilling.	Preferred because residue ready for landfilling.	Least preferred because residue can require re-treatment.
- extent used elsewhere	No difference among options.	No difference among options.	No difference among options.	No difference among options.
Costs				
o Approximate capital cost	Highest cost.	Medium cost.	Medium cost.	Low cost.
o Approximate maintenance cost	Highest cost.	Low cost.	Medium cost.	Low cost.

TABLE 8
EVALUATION OF INCINERATOR ALTERNATIVES
SCALING OF INDICATOR VALUES OF INCINERATOR OPTIONS

Indicator	Indicator Value	Scaled Value
Risk		
Air		
o Air emissions during abnormal operations		
- from incinerator scrubber failure	Two scrubber trains	High*
	One scrubber train	Low*
Occupational Health and Safety		
o Exposure of workers during abnormal operations workers		
- from leakage of dust from crushing and screening equipment	Crushing and grinding equipment installed	High
	Crushing and grinding equipment not installed	Low
- gas emissions due to scrubber failure	Two scrubber trains	High
	One scrubber train	Low
- gas emissions due to excessively-rapid combustion	Automatic control does not eliminate risk	High
	Automatic control eliminates risk	Low
Service		
Resolution of Problem		
o Reliability		
- maintenance requirements	6 pieces of major equipment	High
	3-5 pieces of major equipment	Medium
	2 pieces of major equipment	Low
- frequency of process upsets or breakdown	Less than 80% onstream time	High
	80% to 90% onstream time	Medium
	Greater than 90% onstream time	Low

*Low = low risk = preferred
High = high risk = not preferred

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TABLE 8--Continued
EVALUATION OF INCINERATOR ALTERNATIVES
SCALING OF INDICATOR VALUES OF INCINERATOR OPTIONS

Indicator	Indicator Value	Scaled Value
o Flexibility		
- to variations in waste characteristics	Not flexible to variations	High
	Some problems with variations	Medium
	No problems with variations	Low
- to variations in waste quantities	Turndown less than 2:1	High
	Turndown 2:1 or higher	Low
- speed of startup/ shutdown	Capable of idling on low fire and of semi-continuous operation	Low
	Capable of idling on low fire	Medium
	Not capable of idling on low fire	High
o Performance		
- destruction and removal efficiency (DRE)	Less than 99.99% DRE	High
	99.99% DRE or higher	Low
- residue characteristics	Residue needs re-treatment at times	High
	Residue needs solidification before landfilling	Medium
	Residue does not need solidification before landfilling	Low
- extent used elsewhere	Not used elsewhere	High
	Used elsewhere	Low
Costs		
o Approximate capital cost*	Above $10 million	High
	$8-$10 million	Medium
	$6-$9 million	Low
o Approximate maintenance cost*	Greater than $30/tonne	High
	$26 to $30/tonne	Medium
	Less than $26/tonne	Low

*Incinerator only.
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1. Fluidized Bed (Revised Case)

This alternative, shown schematically in Figure 3, includes a single waste feed handling and storage system (same for all four alternatives). Downstream of the feed system are two parallel trains of equipment. The first train, processing liquid, some sludge and some solid wastes, consists of a crushing and screening circuit, a fluidized bed incinerator producing unconsolidated ash and low-temperature (760°-870°C) flue gas. The flue gas discharges to a high temperature (at least 1200°C) secondary combustion chamber from which flue gas discharges into flue gas treatment equipment and thence to the stack. The parallel train, processing drums and the remainder of the other wastes, consists of a rotary kiln operating in a slagging mode followed by a high temperature (1200°C) secondary combustion chamber from which flue gas discharges to flue gas treatment equipment and thence to the stack.

The crushing, screening and incinerator circuits contain at least six major pieces of equipment, i.e., crusher, screens, fluidized bed, secondary combustion chamber, rotary kiln and its secondary combustion chamber, which will be operated continuously.

This fluidized bed alternative is rated high risk for the following reasons:

A. Because of the installation of two trains of scrubber equipment, the expected frequency of occurrence of scrubber failure, while low, is twice that expected from an alternative with a single train.

B. The risk of release of dust from crushing and screening equipment is mitigated by including enclosures and a ventilation system in the design. However, under abnormal operating conditions, the expected frequency of dust release, though small, is higher than expected for an alternative without crushing and screening equipment.

C. It should be noted that this alternative is low risk for emissions due to excessively rapid combustion. Gas emissions from the fluidized bed due to excessively-rapid combustion are not possible due to the design. Similarly, they are not expected from the rotary kiln due to installation of feed and burner controls.

This fluidized bed alternative is rated high with respect to maintenance requirements, high with respect to frequency of process upsets, low with respect to flexibility toward variations in waste charateristics, low to flexibility toward variation in waste quantities, medium to speed of startup/shutdown, low to destruction and removal efficiency, medium to residue characteristic and low to extent used elsewhere for the following reasons:

A. Maintenance will be high because there are six major pieces of equipment, enumerated above, which operate under severe conditions.
B. Six pieces of major equipment are subject to process upsets or breakdowns. Onstream time at full capacity is estimated to be less than 80%.
C. This alternative has both a fluidized bed and rotary kiln operating in parallel. It will have excellent ability to handle variations in waste characteristics because the rotary kiln can handle any feed type that the fluidized bed might not be able to handle.
D. Both the fluidized bed and the rotary kiln have at least a 2:1 turndown ratio and so can adequately handle feed rate variation.
E. Both the fluidized bed and rotary kiln require several hours to days to start up from a cold condition in order not to shock the refractory lining; similarly for full shutdowns. The actual length of time depends upon the type of refractory and the owner's operating philosophy. Therefore, both units give better performance under continuous

operation. However, in both units, waste feed can be shut off abruptly without causing harm as long as the design incorporated auxiliary fuel burners to take over and maintain temperature. Therefore, both units can adequately react to situations that require emergency cutoff of field.

F. The fluidized bed produces an unconsolidated ash that should be solidified prior to landfilling. The rotary kiln, if operated in a slagging mode, produces a slag that can be landfilled without additional treatment.

G. Although there is little data available to show that a fluidized bed incinerator alone can attain a 99.99% DRE on a wide variety of hazardous waste feeds, there is ample evidence that addition of a high temperature secondary combustion chamber (as in the revised case) will achieve 99.99% DRE. Similarly, the parallel rotary kiln can achieve 99.99% DRE.

H. Fluidized bed incinerators are widely used in the chemical, petroluem and metallurgical industries.

Because of the extra equipment that needs to be installed and operated, this alternative ranks high (high cost) with respect to capital and maintenance costs at $10.5 million and $32/tonne, respectively.

2. Rotary Kiln with Secondary Combustion Chamber

This alternative has a single train consisting of waste feed storage and handling (same for all four alternatives), and a rotary kiln in series with a secondary combustion chamber (SCC). The flue gases from the secondary combustion chamber discharge to flue gas treatment equipment and thence to a stack. The kiln and SCC operate at temperatures in the range 1000° to 1400°C. The kiln operates in a "slagging" mode with a molten slag pool at the downsteam end from which the slag discharges and solidifies outside the kiln.

This is a low risk alternative for the following reasons:

A. There is only a single train of flue gas treatment equipment; therefore, the expected frequency of gas release due to scrubber failure is less than the expected frequency for other alternatives which have two parallel trains.
B. There is no crushing and screening equipment to generate dust.
C. The rate of combustion of feeds can be kept under control by including automatic control of feed rate and of combustion in the design.

It has low maintenance requirements and few process upsets and breakdowns because the incinerator has only two major pieces of equipment (namely, the kiln and secondary combustion chamber). Typical onstream time for this type of equipment is 80 to 90 percent.

The rotary kiln/SCC is rated low (i.e., favorable) for flexibility toward variation in waste characteristics because, in a single train, it can handle all the types of feed - drums, solids, sludges, and liquids - that make up the OWMC waste. The wastes can be fed directly into the kiln without pretreatment such as crushing and screening. The kiln is adaptable to a variety of feed mechanism designs so that it can receive all the types of OWMC feed.

It is rated low with respect to variation in feed quantities because it has a turndown ratio of about 2:1.

It is medium with respect to speed of startup and shutdown. In order not to thermally shock the mass of refractory in the kiln and secondary combustion chamber, it normally takes hours to days to start up from a cold condition and to cool down. The actual length of time depends upon the type of refractory and

the owner's operating philosophy. Once heated up, the incinerator can be taken off-line for extended periods and idled on low fire.

It is rated low for destruction and removal efficiency (DRE). A mass of data has been accumulated showing that the kiln/secondary combustion chamber combination can achieve 99.99% DRE on even the most difficult-to-burn compounds.

Residue characteristics rate low because the kiln, when operated in a "slagging" mode, can produce a residual slag that solidifies to a solid that can be landfilled without prior solidification.

The rotary kiln alternative rates low with respect to extent used elsewhere. In fact, it is the most widely-used technology for hazardous waste incineration.

The ratings for cost is medium and low, respectively. Estimated capital cost is $8.0 million and estimated maintenance cost is $25/tonne.

3. Liquid Injection

This alternative includes waste feed storage and handling and two trains of incinerator equipment in parallel. One is a liquid injection incinerator with flue gases discharging to common flue gas treatment equipment and thence to a stack. This train handles only low-ash liquid wastes. The other train is a rotary kiln in series with a secondary combustion chamber with flue gases discharging to common flue gas treatment equipment and thence to a stack. This train handles all the other wastes--drums, solids, sludges, and some liquids. The kiln operates in a "slagging" mode.

This liquid injection alternative is rated low for the following reasons:

A. The design is such that the flue gases from both liquid injection and rotary kiln incinerators discharge into one common flue gas treatment train. With one flue gas treatment train, the expected frequency of gas release, due to scrubber failure is lower than the expected frequency from two scrubber trains.
B. There is no crushing and screening equipment to generate dust.
C. The rate of combustion of feeds can be kept under control by including automatic control of feed rate and combustion.

It is rated medium with respect to maintenance requirements because, although it has only three pieces of major equipment, they operate under severe high temperature and corrosive operating conditions. The refractory linings require regular maintenance.

This alternative is rated medium with respect to frequency of process upsets or breakdowns because it has three pieces of major equipment to keep on line. Typical onstream time for the liquid injection equipment alone is above 90 percent. However, considering the parallel rotary kiln equipment, expected overall onstream time is 80 to 90 percent.

It is rated low for flexibility toward variation in waste characteristics because it can handle all the types of OWMC waste. It is rated low with respect to variation in feed quantities since it has a turndown ratio of 2:1.

It is medium with respect to speed of startup and shutdown. Both the liquid injection and rotary kiln equipment have refractory linings that should be heated slowly from a cold startup and cooled down slowly. The actual length of time

required depends upon the type of refractory and the owner's operating philosophy. Once heated up, either piece of equipment can be taken off-line for extended periods and idled on low fire. It is rated low for DRE because it can achieve 99.99% DRE.

Residue characteristics rate low because the residue is the slag from the kiln which, after cooling and solidifying, can be landfilled without prior solidification treatment.

The rating for cost is medium with values of $9.2 million estimated capital cost and $28/tonne maintenance cost.

This alternative rates low (i.e., favorable) with respect to extent used elsewhere because both components (liquid injection and rotary kiln) are used extensively elsewhere for hazardous waste incineration.

4. Pyrolytic Fixed Hearth

This alternative includes waste feed storage and handling (same for all four alternatives) followed by two parallel trains of pyrolytic fixed hearth incinerators each consisting of a primary and secondary chamber with the flue gases discharging into two sets of flue gas treatment equipment and thence into a stack. Two trains are used because the typical pyrolytic unit has a capacity less than the 30,000 tonnes/year required by OWMC. Ash is discharged from the primary chambers in unconsolidated form.

This alternative is rated high risk for the following reasons:

A. There are two trains of air pollution control equipment; therefore, the expected frequency of gas release due to scrubber failure, while low, is twice the expected frequency for a single-train alternative.

B. In the primary combustion chamber, there is a risk of uncontrolled combustion and even explosion because the unit normally is operated under conditions where the gas in the primary chamber is explosive. Accidental in-leakage of air or failure to purge the chamber on shutdown are two conditions that have caused uncontrolled combustion followed by expulsion of hazardous combustion gases into the surrounding atmosphere.

It is rated medium with respect to maintenance because although it has four pieces of major equipment, the primary chambers can be fixed units operating under less severe, lower temperature conditions than the secondary chambers. The secondaries are refractory-lined.

The pyrolytic fixed hearth is rated medium with respect to frequency of process upsets or breakdowns because there are four pieces of major equipment. Typical onstream time should be about 80 percent.

The pyrolytic fixed hearth is rated high with respect to flexibility toward variation in waste characteristics for two main reasons. First, in a pyrolytic incinerator the primary chamber operates under starved-air conditions in contrast to the other alternatives which operate with high percentages of excess air. Under starved-air operation, control is difficult to maintain with major variation in feed composition, particularly variations with respect to heat content. Second, there are certain types of waste, such as pulpy solids, which are not easily pyrolyzed and which, if fed in large quantities, may produce solid residues which would have to be recovered and re-treated.

It rates low for flexibility to variations in waste quantities because it has at least a 2:1 turndown ratio and rates medium for speed of startup and shutdown. Because the secondary

are refractory-lined, the units should be started up slowly from a cold shutdown. Startup time can vary from hours to days depending on type of refractory and the owner's operating philosophy. Once up to temperature, they can be taken off-line and idled if necessary.

The units regularly achieve 99.99% DRE on most hazardous wastes.

This alternative rates high with respect to residue characteristics. The residue is produced in the primary chamber which is operated under starved-air, i.e., reducing, conditions. Therefore, the residue contains solid carbon and, under improper operating conditions, may contain unreacted materials; therefore, the residue will periodically require recovery and re-treating in the incinerator. It is normally in a consolidated form that often can be landfilled without further treatment.

The technology is widely used elsewhere particularly in small industrial applications. It is also rated low on capital and maintenance costs with values of $7 million and $23/tonne, respectively.

Selection of Preferred Technology

Based on the results of this evaluation, the preferred incinerator technology is the rotary kiln with secondary combustion chamber.

The pyrolytic fixed hearth alternative which includes two fixed hearth units in parallel appears to carry the most risk of the four since it has risks associated with scrubber failure and explosion in the primary chamber. It does have the advantage of being a lower cost alternative than the rotary kiln technology, but this does not appear to be significant enough to offset the risks involved. Therefore, it should be rejected on the basis that it conflicts with the goal of minimizing risk to human health.

One main reason the rotary kiln incinerator alternative is preferred over the fluidized bed alternative is because the latter includes both a fluidized bed and a rotary kiln. Therefore, it has more equipment (six pieces of major equipment versus two for the rotary kiln) to accomplish the same purpose. In addition to the cost of the extra equipment, there are the added risks associated with scrubber failure (which makes this alternative less likely to comply with the goal of minimizing risk to human life). Additionally, there are the added maintenance requirements and the added downtime associated with the extra equipment; both of these detract from the goal of maximizing service. There do not appear to be any offsetting advantages. In summary, the rotary kiln alternative accomplishes the same results as the fluidized bed at less risk and better service. Therefore, the fluidized bed was rejected.

The revised liquid injection alternative has many of the advantages of the rotary kiln/SCC since it includes a liquid injection incinerator in parallel with a rotary kiln/SCC with the flue gases from both units discharging into common flue gas treatment equipment and stack. Therefore, the risks should be the same as for the rotary kiln/SCC alternative. Consequently, the comparison between the two must be based on the service aspects. Downtime for maintenance requirements would be higher for the three major pieces of equipment in the liquid injection alternative. Also the capital and maintenance costs would be higher. For these three reasons, all of which detract from the goal of maximizing service, and lacking any offsetting advantages, the liquid injection incinerator is not considered to be as attractive as the rotary kiln/SCC alternative. Hence, the liquid injection incinerator was rejected.

Therefore, the rotary kiln incinerator with secondary combustion chamber was chosen as the preferred incinerator alternative.

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APPENDIX A

DESCRIPTIONS OF INCINERATOR TECHNOLOGIES

APPENDIX A

DESCRIPTIONS OF INCINERATOR TECHNOLOGIES

In the following pages, descriptions are given of the incinerator technologies in the long list as follows:

- *Fluidized Bed
- *Liquid Injection
- *Calciner/Cement Kiln
- *Plasma Arc/Microwave Plasma Discharge
- *Rotary Kiln with Secondary Combustion Chamber
- *Multiple Hearth Incinerator
- Pyrolytic Fixed Hearth with Secondary Combustion Chamber
- Rocking Kiln
- *Molten Salt Incinerator

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* Copied from Reference No. 1

FLUIDIZED BED

Process Description

A fluidized bed incinerator (Figure 3.4.6) consists of a vertical refractory lined vessel containing a bed of granular material resting upon a distributor plate. Combustion air is introduced at the bottom of the incinerator and rises vertically through the distributor plate into the granular bed. Silica sand is normally used as the bed material, but limestone or other materials have also been used. If the waste contains inorganic materials, the bed can, depending upon bed material, be replaced gradually with the inorganic material generated through incineration. Continuous bed material removal and make up is practiced for this situation.

The upward flow of air through the bed causes fluidization of the bed material and rapid mixing of the waste material, air and bed material. The waste is normally fed directly into the bed or above the bed. Combustion takes place within the bed with some combustion being completed in the freeboard area above the bed (a function of the waste characteristics, bed material and design of the unit). The temperature within the bed typically ranges from 600° to 900°C.

Waste Inputs

Fluidized bed incinerators can be used to dispose of solid, liquid, sludge, slurry, and gaseous wastes. Solid materials may require processing for size reduction to facilitate feed to the fluidized bed. This technology may be considered for thermal processing of the following wastes (UCD Classification): 211-217; 221-228; 241, 254, 262, 281; 289; 455.

Effluent and Residuals

Ash and ground fines of bed material are carried out of the fluid bed incinerator with the combustion product gas stream to the scrubbing systems which may include electrostatic precipitators for particulate removal, wet or wet/dry scrubbers for particulate and other chemical pollutant scrubbing. Scrubber waste water from wet scrubber systems may require further treatment before being discharged from the facility.

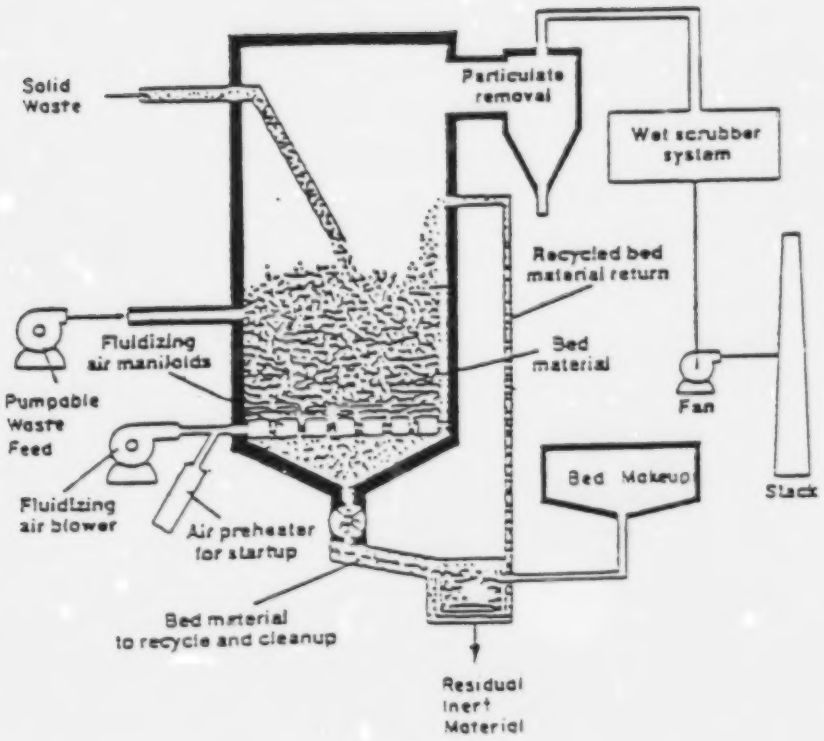


FIGURE 3.4.6 : FLUIDIZED BED INCINERATION SYSTEM

The physical and chemical nature of the resulting ash and fines will be a function of the waste material chemical properties and the material used in the bed. Chemical reactions occurring during the combustion process in the bed may form other chemical compounds depending upon the waste and bed material. This permits matching of specific waste streams to bed material to achieve a combination of combustion and calcining that may produce an inert ash or reusable product the same as described under Calcination/Cement Kiln.

Implementation, Reliability

Fluidized bed incinerators have been used successfully for refinery, paper mill and sewage treatment plant sludge incineration. They have also been used as ore roasters, calciners, etc. There has been some attempt at aqueous organic waste incineration.

Although fluidized beds have been used for many years in various industries, their use in hazardous waste incineration is still essentially at a demonstration level. It is generally agreed, however, that this approach to waste incineration offers significant potential for the future for certain classes of wastes.

Process Applications

The fluidized bed incinerator may be considered for the incineration of liquids, sludges, and wastes containing a high ash content.

Fluidized beds are primarily used to dispose of sludges from municipal wastewater treatment plants, petroleum refineries, and pulp and paper mills. There is limited data related to their use as waste incinerators. Wastes which have reportedly been burned in fluidized beds, however, include organic wastes from pharmaceutical manufacturers, phenolic wastes, and methyl methacrylate.

Economic Factors

Capital costs for a waste fluidized bed incinerator facilty are highly dependent upon the waste quantity, type of waste, and the necessary pollution control system to meet environmental needs that are to be handled at the facility.

Maintenance costs are high for these facilities on a dollar basis, but on a per unit weight of waste treated are relatively low provided a reasonably high level of utilization of the equipment is maintained.

Energy costs are highly dependent on the calorific value of the waste, percent water in the waste, and available waste to offset purchased fuel that might be required for some waste treated. These costs are very dependent upon the managerial control of scheduling various wastes to minimize purchased energy requirements while insuring that the mix of chemicals will not result in final combustion products that may destroy slag properties, ash properties, or cause deposits in waste heat boilers or scrubbing systems affecting their performance.

Energy Requirements

Energy requirements are highly dependent on the calorific value of the waste to be destroyed and the availability of waste fuels. Proper management of scheduling will reduce energy requirements to a minimum.

Resource Recovery Potential

In some instances, the fluidized bed incinerator can be designed to recover specific compounds from the bed when the bed material used is capable of chemically reacting with the waste material to be destroyed at the temperatures involved. This end product from the bed, depending upon the waste and bed materials, may be directly landfilled or reused or further treated depending upon its chemical and physical properties.

As in any thermal process with high temperature flue gas, waste heat can be recovered in the form of steam of hot water or used to preheat combustion air.

Environmental Factors

Fluidized bed incinerators are a well-proven technology with many operating plants throughout the world. Environmental factors relate specifically to the resulting ash of the incinerated waste, liquid discharge from wet scrubber systems, if employed, particulate removed from the flue gas stream, and flue gas emissions to the atmosphere.

Ash disposal is to secure landfill sites for ash that is not suitable for reuse; to municipal solid waste landfill sites for inert ash; to metal recovery or reuse in other forms where warranted.

Latest technology for flue gas scrubbing results in minimum liquid waste to be treated (or no liquid waste at all) leaving particulate to be disposed of in the same manner as the ash. Air emissions are minimized through the use of proper air pollution control systems, sized and matched to the type and quantity of waste to be handled by the facility.

Regulatory agencies have accepted many fluidized bed incinerators as latest state-of-the-art incineration technology when coupled with appropriate air pollution control systems.

LIQUID INJECTION

Process Description

Liquid injection represents a special application of a waste thermal processing technology (Figure 3.4.5). A key component of the liquid injection incinerator is the waste atomization device or nozzle. The purposes of injecting the liquid as a spray are to:

- break-up the liquid waste into fine droplets, and
- introduce the liquid wastes into the incinerator at a specific location

Normally, liquid injector incinerators consist of two stages. The primary chamber is usually a burner where combustible liquid and gaseous wastes are introduced. Noncumbustible liquid and gaseous wastes are usually introduced downstream of the burner into the secondary chamber. Single-stage incinerators are used for systems handling only combustible wastes.

The configuration of a liquid injection incinerator can be horizontal, vertical upfired, vertical downfired, or sloped. The selection of configuration usually depends on the characteristics of wastes.

In general, waste liquid cannot be oxidized effectively in conventional burners. A high heat release burner is usually necessary for complete combustion of these liquid wastes. The burners must be located to prevent flame impingement on walls and, in the case of multiburner systems, interference with one another.

Waste Inputs

Liquid injection incinerators are versatile devices which can be used to dispose of many pumpable wastes, such as contaminated water and waste solvents. This technology may be considered for thermal processing of the following wastes (UCD classification): 211-217; 221-228; 281.

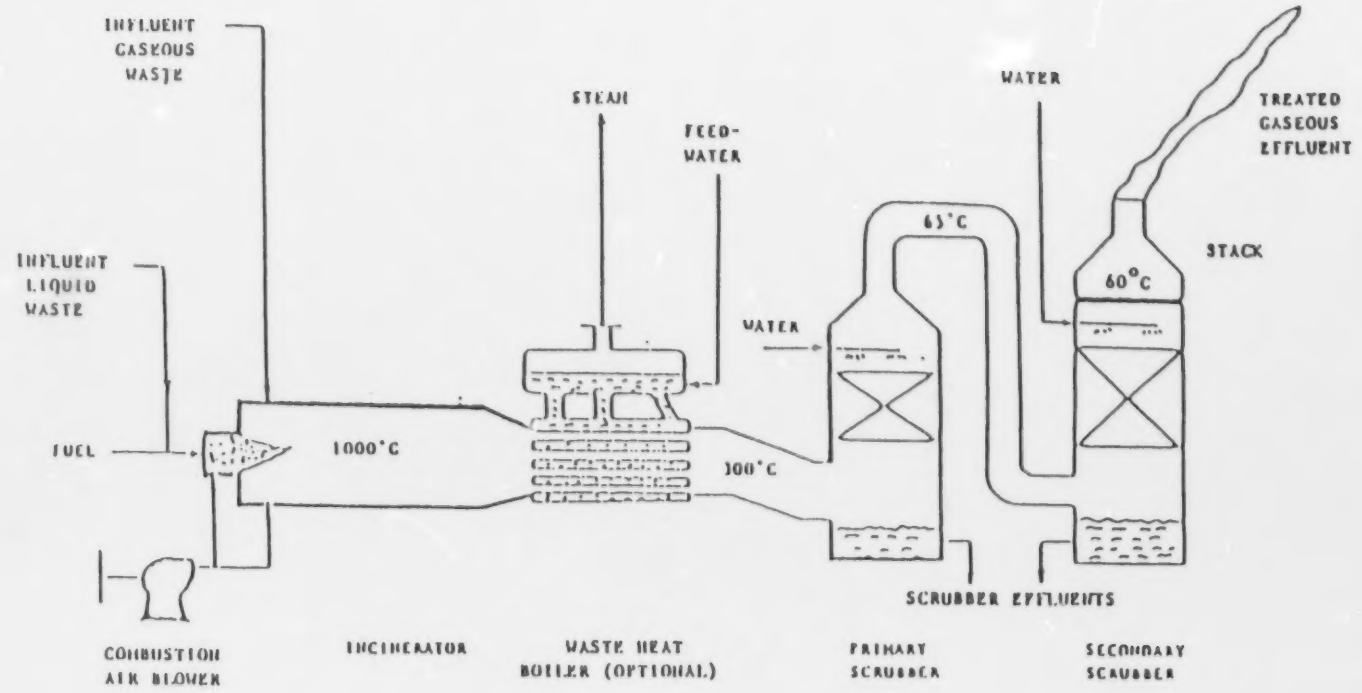


FIGURE 3.4.5 : LIQUID INJECTION INCINERATOR WITH HEAT RECOVERY

Effluent and Residuals

The liquid injection incinerator system produces two or three effluent waste streams. Liquid and gaseous effluent streams are related to the air pollution control system incorporated to treat air emissions. Wet scrubbing systems may produce a relatively concentrated liquid effluent that requires treatment, or they may incorporate a recirculation and drying feature that eliminates the liquid stream (i.e., contaminants are then removed as dry particulate). The gaseous effluent stream after being treated by the air pollution control system is discharged by means of a stack. The solid inorganic residues comprise the third effluent stream which are made up primarily of slag particulates and other nonburnables and scrubber dry particulate which require ultimate disposal, generally to a land disposal facility.

Implementation, Reliability

Liquid injection incinerators represent a widely used proven technology for pumpable waste treatment. Liquid injection is in daily use throughout the U.S.A. both at industrial locations and central treatment facilities. Liquid injection systems contain no moving parts and generally require the least maintenance of all types of incinerators. On-line destruction efficiencies of over 99.99% have been achieved.

Liquid injection incinerators are highly sensitive to waste composition and flow changes. Thus, storage and mixing tanks are necessary to ensure a reasonably steady and homogeneous waste flow.

Process Applications

Liquid injection incinerators are generally applicable to the ultimate disposal of combustibles in pumpable liquid wastes. Due to their size, liquid injection systems are usually dedicated to specific plant applications.

This type of incinerator can also be used to dispose of solid wastes, either by melting or by dissolving them into a liquid material. When preheating a

waste, it is essential to ensure that undesirable preliminary chemical reactions such as polymerization, nitration, etc., will not occur. Provisions should also be made to prevent the release of gases during preheating.

Wastes treated by liquid injection incinerators include PCBs, chlorinated hydrocarbons, brominated hydrocarbons, pesticide and insecticide plant waste, vinyl chloride, fluorinated herbicide wastes, and nitrochloride-benzene wastes.

Economic Factors

The size of liquid injection incinerators is usually in the range of 1 to 150 GJ/h. Smaller units are usually factory fabricated package units. Capital costs are dependent upon environmental requirements for the waste to be destroyed. Maintenance cost is usually low.

Operating costs are very dependent upon the calorific value of the waste and its water content, etc. Operation often requires only one or two trained personnel.

Energy Requirements

Energy requirements vary with the type of waste processed. No fuel is required for self-combustible wastes.

Resource Recovery Potential

Liquid injection incinerators have been designed to recover hydrochloric acid, hydrobromic acid, phosphoric acid, sodium carbonates and precious metal catalysts. The recovery of waste heat energy as steam is also possible for liquid injection incinerators.

Environmental Factors

Liquid waste of the type to be destroyed in a liquid injection incinerator normally has little resulting ash which is removed in the scrubber system either in the dry state or as solids in the liquid stream from a wet scrubber.

Liquid injection incinerators are a well-proven technology with many operating plants throughout the world for treatment of liquid combustible waste. The environmental factors relate specifically to the resulting ash of the incinerated waste, liquid discharge from wet scrubber systems, if employed, particulate removed from the flue gas stream and flue gas emissions to the atmosphere.

Latest technology for flue gas scrubbing results in minimum liquid waste to be treated (or no liquid waste at all), leaving only particulate to be disposed of. The air emissions are minimized through the use of proper air pollution control systems, sized and matched to the type and quantity of waste to be handled by the facility.

Regulatory agencies have accepted many liquid injection incinerators as latest state-of-the-art incineration technology when coupled with appropriate air pollution control systems.

CALCINATION/CEMENT KILN

Process Description

Calcination, a thermal process that makes use of an existing cement kiln, is generally applied to the incineration of aqueous liquids and sludges requiring elevated temperatures.

There are three basic types of calcination units; open hearth, rotary kiln and fluidized bed. Illustrated in the flow diagram (Figure 3.4.4) is a typical rotary kiln type cement calcination unit. Feed is introduced at the cool end of the kiln at the point where the gases and vapors are emitted. A high degree of turbulence, agitation and surface-to-gas contact is achieved with the inclination of the cement kiln. The partially calcined material travels slowly down the kiln while being exposed to increasing temperatures and is finally discharged at the end nearest the heat source. Feed addition and product removal are continuous. Kiln temperatures are generally in the 800-2000°C range. The off-gas residence time in the high temperature zone is 15-20 seconds.

Waste Inputs

Cement kilns can be used to incinerate limited quantities of certain aqueous solutions, slurries, and sludges with the objective of chemically reacting some of the gaseous pollutants and the ash from the waste into the cement clinker. Tests have been performed on some units with PCB wastes in which the cement clinker absorbs, through chemical reaction, most of the remaining PCBs after combusting the waste as part of the fuel source. Waste input is limited to the impact it has upon the properties of the ultimate product (i.e., cement clinker). Waste should be limited to those forms, types and quantities that are well within the production capacity of cement kilns. This technology is generally appropriate for thermal processing of the following wastes (UCD Classification): 214-216; 225; 227; 241; 281.

Other calcine kilns for recalcination of lime or other products may be used in a similar fashion as noted for cement kilns. Again, the use is restricted to the end product being produced, as the waste to be disposed of must not affect the end product properties.

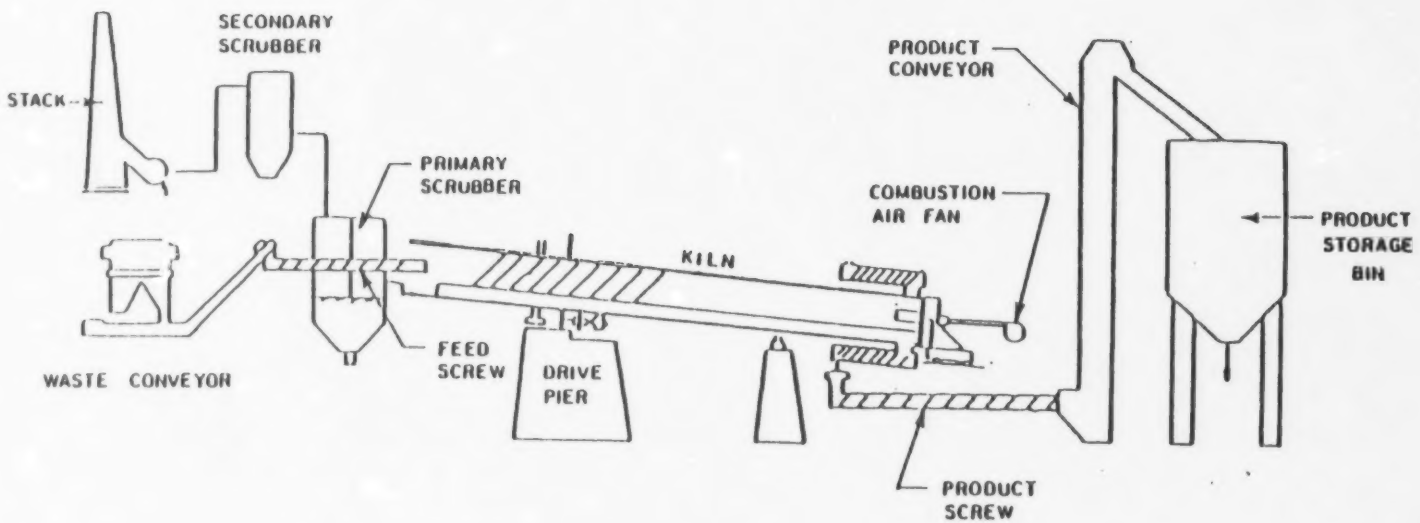


FIGURE 3.4.4 : ROTARY KILN CALCINER

In certain instances, the calcination/cement kiln concept can be used where the end product is not for sale but would be placed in a appropriate landfill site. In such a case, a higher quantity of waste can be disposed of in the kilns.

Effluent and Residuals

Calcination systems require extensive air pollution control equipment similar to that required for rotary kilns, as previously described. Additional pollution control may be required if waste is introduced at the cool end of the kiln and some of the combustion products and volatilized compounds cannot be fully reacted at the temperatures and residence time available at that end of the kiln. Waste should be restricted to that which will fit within the temperature and residence time limits of the kiln.

In most cases, where the waste combustion products are absorbed by the end product of the kiln, the resulting product is generally very stable for use in its original purpose or for storage or land disposal. Tests have indicated that some wastes, when introduced to cement kilns, have no impact upon the end product properties and result in virtually 100% destruction of the waste.

Implementation, Reliability

There has been test work to study the applicability of cement kilns for hazardous waste disposal. Cement kilns are a potential thermal p ocess system for waste management because of the high temperatures, relatively long residence time, and the chemical reactions of the ash and some of the waste products of combustion wi'h the cement clinker.

Calcination is a well established process with many industrial waste treatment applications. It is a versatile one-step process which can be utilized for controlled types and quantities of wastes. Existing cement kilns can be utilized with little modification for waste processing.

Process Applications

Calcination processes have been used in the recalcination of lime sludges from water treatment plants; coking of heavy residues and tars from

petroleum refining operations, concentration and volume reduction of liquid radioactive wastes, and treatment of mixed refinery sludges.

Combustible wastes have been burned in commercial cement kilns as auxiliary fuel. The burning conditions within the kilns are generally suitable, based on temperature and residence time, to destroy combustible hazardous and toxic wastes. Although burning conditions within the kiln are usually adequate to destroy hazardous materials, industry may be concerned about quality control in the waste and its impact on the end product reliability. Of particular concern is the chloride content of waste. Cement kiln operations presently limit the chloride content of the waste to less than 2% by weight.

Economic Factors

Adapting existing cement kilns to waste management represents a potential cost effective treatment approach. Capital investment would be necessary for upgrading existing facilities to improve materials handling and air pollution control. To build a new facility for waste disposal only, the capital and operating costs will be sensitive to the concentration of the material to be calcined and the waste materials being treated.

Maintenance costs will approach those for existing cement kilns or other calcine projects in industry where the intent is to build a separate waste facility utilizing these processes. Maintenance costs will be substantially less where existing cement kilns and calcine operations are utilized for disposal of limited quantities of specific wastes. The maintenance costs relative to the latter possibility will be greater than present industry maintenance costs by that amount required for the upgraded facilities, waste material handling and air pollution control.

Operating costs will vary little from existing industry costs for a separate waste facility. Operating costs at existing cement kilns or calcine plants will be essentially the same as for their present operation (i.e., a NIL value for the operating costs relative to the waste portion of the operation) plus the additional manpower for receiving and handling of the waste material to be disposed of.

Energy Requirements

Energy requirements will be highly dependent upon the water and organic content of the waste streams. Where the facility is added to an existing industrial process, the limitations imposed upon the waste stream will include the need for high calorific value waste to eliminate purchasing additional fuel. Where the waste facility is to be a "stand-alone" facility it would be necessary to balance high calorific wastes, lower calorific wastes, and wastes with high quantities of water, to minimize energy demand from purchased fuel.

Resource Recovery Potential

There is little resource recovery potential with respect to cement kilns and calcinors as the existing industrial facilities already sell their end product and recover heat from the process for combustion air preheating or other uses. The primary potential for these facilities is that they provide existing facilities for the incineration of specific wastes.

Environmental Factors

As a dedicated waste disposal facility, cement kilns give a product that is suitable for sale or disposal to landfill. A large volume reduction is achieved and the resulting calcined products typically show low leachability. Additional air emissions are invariably produced during the process, and adequate treatment systems must be employed.

PLASMA ARC/MICROWAVE PLASMA DISCHARGE

Process Description

There are two basically different types of plasma generator, namely, the plasma arc reactor and the microwave plasma reactor.

A plasma arc reactor (Figure 3.4.10) is a device that utilizes electrical energy to generate a high temperature plasma arc - up to 28000°C - which in turn is used to destroy wastes by pyrolyzing them. In this device, a co-linear electrode arrangement creates an electric arc. As gas passes the arc, electrical energy is converted to thermal energy through adsorption by the gas molecules which are activated into ionized atomic states. The resulting gas is in the plasma state. As the activated components of the plasma decay, their energy is transferred to the waste materials exposed to the plasma under oxygen-starved conditions. The unit can pyrolyze gaseous, liquid and solid feeds.

On the other hand, in a microwave plasma reactor, microwave electronic fields are used to accelerate the free electrons found in trace amounts in all gases. In the process, gaseous breakdown occurs and a plasma is formed in which the free electrons have temperatures in excess of 20000K whereas the bulk gas (neutral) in the plasma is much cooler (1000 - 2000°K). Waste organic gases, fed in a bulk carrier gas (usually oxygen), interact with the free electrons to fragment the organic molecules. The fragments in turn react with atomic oxygen to become completely oxidized.

In the plasma arc reactor, the plasma arc flame is generated by the following steps:

- Gas (argon, helium, hydrogen, oxygen, etc.) is introduced in small quantities to create a swirling motion that keeps the plasma flame in the centre of the torch, away from metal parts and side walls of the reaction chamber.

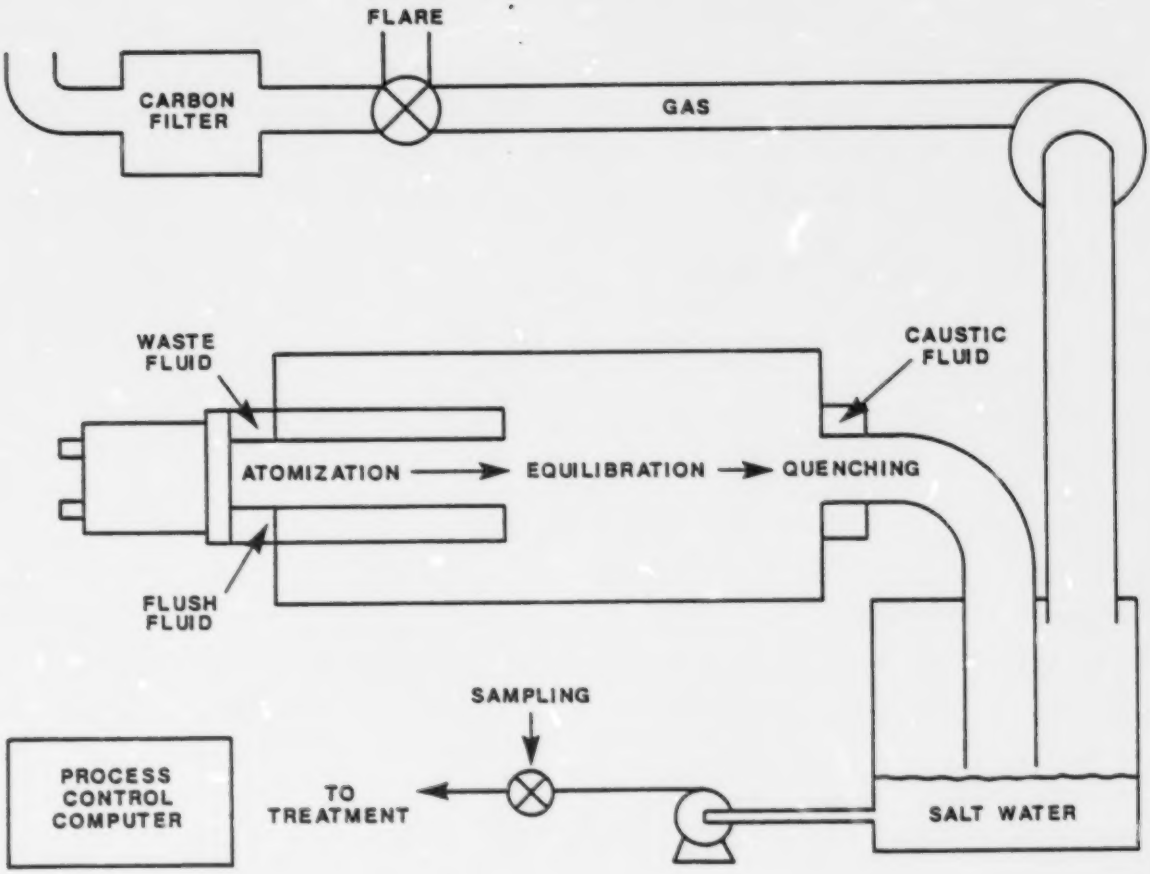


FIGURE 3.4.10 : PYROPLASMA® PROCESS SCHEMATIC.[17]

- An electrical discharge is established (plasma arc flame) and maintained between the electrode inside the torch and any external electrical conductor.

- The plasma flame then converts electrical energy into heat energy in an extremely efficient manner.

In the plasma arc reactor, the ultra high arc temperature of 50,000°C is sustained to provide the endothermic heat requirements of pyrolysis. Intense ultraviolet radiation enhances volatilization and thermal cracking of organic matter. In the pyrolytic zone, the high temperatures cause reduction of all species to atomic entities prior to recombination into low-molecular-weight gases. Plasma arc technology has to date only been tested on liquid organic wastes. Concurrently, a plasma arc system could return energy up to several times the electrical energy input. Recoverable energy would be in the form of sensible heat from the combustible byproducts.

The basic elements of a microwave plasma discharge reactor are:

1. a microwave generator or source of power;

2. a waveguide which leads the microwave power from the generator to a resonant cavity, which surrounds the reactor;

3. a reaction chamber, which must be made of silica or quartz to minimize dielectric losses;

4. a system for generating or feeding vapors, or reactants or condensed phases into the reaction chamber;

5. a system for controlling pressure and flow; and

6. a system for collecting reaction products.

Waste Inputs

Plasma arc reactors have been tested on liquid hazardous waste feeds. They have been operated with solid feeds in non-hazardous metallurgical applications.

Microwave plasma reactors can handle only gaseous wastes.

Effluent and Residuals

The product gases from plasma arc reactors are combustible gases with some heating value and may be useful as an auxiliary fuel. The gaseous effluent stream requires flue gas treatment to remove acid gases, particulates, and metals prior to discharge. A liquid effluent from the scrubber may require pretreatment (e.g., pH adjustment) prior to discharge to a wastewater treatment plant. The residual slags from plasma arc reactors are predominantly inorganic and require ultimate disposal to landfill.

The product gases from microwave plasma reactors are not combustible. They require flue gas treatment to remove acid gases.

Implementation, Reliability

Plasma arc reactors have been demonstrated in the laboratory and pilot plant and offer promise as a future thermal processing option in waste management. They are now in the developmental stages. Plasma technology has been applied to the destruction of industrial wastes in at least one location in the United States.

Because wastes can be variable in both chemical and physical characteristics, considerable research will be required to assure the reliability of microwave discharge techniques for complete combustion. In one of the first studies of the use of microwaves to treat hazardous wastes, microwave discharge was applied to nerve gas compounds and percent conversions ranged from 62 - 99.5%. The outlook for this technique is

encouraging, particularly for highly toxic materials that cannot be handled in any other way. It is too early to predict the possible range of applications or the specific waste streams which could be treated cost effectively.

Process Applications

U.S. EPA funded projects are currently investigating both plasma arc and microwave plasma decomposition of waste. Experimental systems are designed to handle organic and metal-organic liquids and vapours. They could possibly be extended to handle fine powders or particulates.

The small capacity of even a large microwave facility certainly precludes general use of the process for a large commercial size facility. There may be specialized applications for small quantities of oxidizable wastes which are not emenable to high temperature incineration.

Economic Factors

Since the plasma reactors are relatively new technologies, cost estimates have been developed only by the manufacturer.

Cost estimates by the manufacturer for a plasma arc reactor are as follows:

Capital: $1.6 million (U.S.) for 1.5 MW mobile unit at 0.75 tons waste/hr.

Operating: Based on three-year cost recovery and up to 50% chlorine levels in waste:

Total $ per unit of feed	2000 hr/yr	6000 hr/yr
	$0.9 - 2.1 million	$1.4 - 4.8 million
	$600 - $400/ton	$300 - $1050/ton

Energy Requirements

Plasma arc systems could have large energy requirements. As development of the technology progresses, energy requirements will be more clearly defined.

Resource Recovery Potential

Plasma arc reactors can generate fuel gases from selected wastes which have a heating value. Both types of reactors offer the possibility of energy recovery from high temperature flue gases.

Environmental Factors

Microwave plasma treatment of waste materials containing halogenated compounds can give rise to gaseous emissions that include Cl_2O, $COCl_2$, HCl, Br_2, BrO_2, and Br_2O. Waste materials containing nitrogen compounds are likely to give rise to nitrogen oxides. The high temperatures present in both plasma arc and microwave plasma reactors may tend to cause excessive vaporization of metals from hazardous wastes.

ROTARY KILN

Process Description

The rotary kiln incinerator is a cylindrical refractory-lined shell mounted with its axis at a slight slope from the horizontal. It can be fueled by natural gas, oil or waste oil, or pulverized coal.

The basic system consists of the rotary kiln and a secondary combustion chamber. Solid wastes, sludges, waste drums, and liquid wastes can be fed into the rotary kiln. As these wastes move through the kiln, organic matter is burned. Liquid and gaseous wastes and purchased fuels are used as auxiliary fuel in both the kiln and the secondary chamber.

If the solid wastes contain excessive entrained liquid, a drying section can be incorporated into the system, usually in front of the rotary kiln. In the drying section, water and volatile organics are vaporized. These vaporized materials bypass the rotary kiln and are fed into the secondary combustion chamber. Liquid and gaseous wastes can be introduced into the kiln or the secondary combustion chamber.

The secondary chamber is used to achieve complete combustion of volatile organics and organics carried by gas-borne particles. Liquid wastes are atomized and burned in suspension. If high energy content combustible waste liquids are not available, purchased fuels are required.

Waste Inputs

Rotary kilns (Figure 3.4.1) are a very versatile type of thermal process system. They are capable of handling slurries, sludges, bulk solids of varying size, containerized wastes, combustible and noncombustible liquid wastes. This technology has been successfully used for thermal processing of the following wastes (UCD classification): 211-217; 221-223; 241-245; 248; 251; 254; 261-264; 281-289; 446; 454-455; 512-513; 521; 523; 528; 531-532.

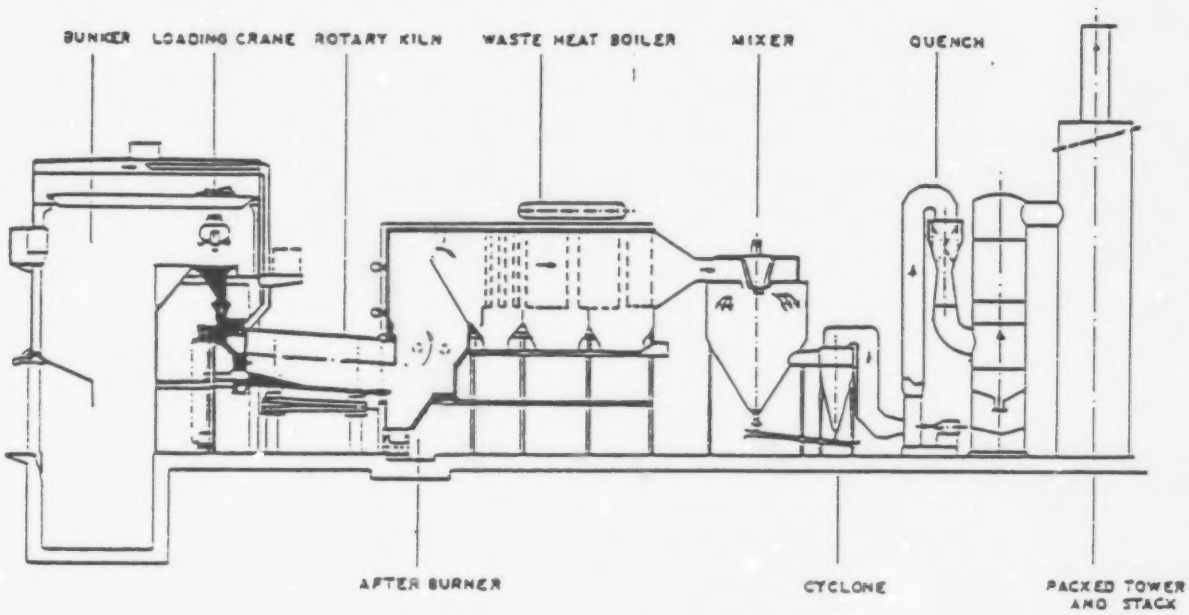


FIGURE 3.4.1

EXAMPLE OF MODERN HAZARDOUS WASTE ROTARY KILN INCINERATOR WITH WASTE HEAT RECOVERY AND HIGH EFFICIENCY WET/DRY FLUE GAS SCRUBBER (BIEBESHEIM, WEST GERMANY). (REPRODUCED COURTESY OF VON ROLL A.G.)

Effluent and Residuals

The rotary kiln system produces two or three effluent waste streams. Liquid and gaseous effluent streams are related to the air pollution control system incorporated to treat air emissions. Wet scrubbing systems may produce a relatively concentrated liquid effluent that requires treatment, or they may incorporate a recirculation and drying feature that eliminates the liquid stream (i.e., contaminates are then removed as dry particulate). The gaseous effluent stream after being treated by the air pollution control system is discharged by means of a stack. The solid inorganic residues comprise the third effluent stream which are made up primarily of slag particulates and other nonburnables and scrubber dry particulate which require ultimate disposal, generally to a land disposal facility.

Implementation, Reliability

Rotary kiln incinerators are a well-proven technology currently applicable to the ultimate disposal of many forms of combustible waste material. At the present time, rotary kilns represent a major incinerator type being used for wastes disposal, either for individual industrial plants, or as a regional central disposal facility.

Regularly scheduled preventive maintenance of kiln refractory and the scrubber systems is vital to long-term consistent high destruction efficiency of wastes. In addition, the mix of wastes fed to the rotary kiln must be carefully controlled (as for any thermal process) to prevent undesirable thermal chemical reactions in the combustion process that also affect slag or ash properties and thus inhibit destruction of the waste or flue gas scrubbing efficiency.

Process Applications

Rotary kiln incinerators are applicable to many organic wastes, or organic wastes containing phosphorus, silicon, sodium, sulphur, halogens (fluorine, chlorine, bromine, iodine).

Rotary kiln incinerators are currently used to incinerate such wastes as: PCBs in capacitors, nitrochlorobenzene tars, TDI reactor tar bottoms, obsolete munitions, obsolete chemical warfare agents (GB, VX, and mustard gas), diphenylamine reactor tar bottoms, acrylonitrile manufacturing wastes, acrylonitrile reactor tar bottoms, alkylated phenol steam still bottoms, phenylamine tar wastes, phenolic tar from 2, 4-D manufacture, epichlorohydrin manufacturing wastes, chlorotoluene production wastes, catch basin grease, nitrite pitch from production of surface active agents.

Economic Factors

Capital costs for a rotary kiln incinerator facility are highly dependent upon the waste quantity, type of waste, and the necessary pollution control system to meet environmental needs at the facility.

Maintenance costs are high for these facilities on a dollar basis, but on a per unit weight of waste treated are quite low provided a reasonably high level of utilization of the equipment is maintained.

Energy costs are highly dependent on the calorific value of the waste, percent water in the waste, and available wastes to offset purchased fuel that might be required for some waste treated. These costs are very depencent upon the managerial control of scheduling various wastes to the kiln to minimize purchased energy requirements while insuring that the mix of chemicals will not result in final combustion products that may affect slag properties, ash properties, or cause deposits in waste heat boilers or scrubbing systems affecting their performance.

Energy Requirements

Energy requirements are highly dependent on the calorific value of the waste to be destroyed and the availability of waste fuels. Proper management of scheduling will reduce energy requirements to a minimum.

Resource Recovery Potential

Ash discharge from the kiln may have a high concentration of metal oxides which may be suitable for recovery of metals. However, since it is the residue from hazardous waste treatment, the ash is considered to be a hazardous waste. Therefore, it can be anticipated that the ash would have to be delisted before being processed to recover metals.

Residual energy in the hot flue gas products may be recovered in waste heat boilers as steam or hot water for use throughout the facility for heating or combustion air preheat purposes. Many modern facilities already incorporate waste heat recovery boilers and combustion air preheaters.

Environmental Factors

Rotary kiln incinerators are a well-proven technology with many operating plants throughout the world for treatment of hazardous combustible waste. The environmental factors relate specifically to the resulting ash of the destroyed waste, liquid discharge from wet scrubber systems, if employed, particulate removed from the flue gas stream and flue gas emissions to the atmosphere.

Ash disposal will be to secure landfill sites for that ash that is not suitable for reuse; to normal landfill sites for inert ash; to metal recovery or reuse in other forms where warranted.

Latest technology for flue gas scrubbing results in minimum liquid waste to be treated (or no liquid waste at all) leaving particulate to be disposed of in the same manner as kiln ash. Emissions to the atmosphere are minimized through the use of proper air pollution control systems, sized and matched to the type and quantity of waste to be handled by the facility.

Regulatory agencies have accepted many rotary kiln incinerators as latest state-of-the-art incineration technology when coupled with appropriate air pollution control systems.

MULTIPLE HEARTH INCINERATOR

Process Description

The multiple hearth incinerator (Figure 3.4.2) has been utilized to incinerate sewage sludges, tars, granulated solids, and some liquid and gaseous combustible wastes. Normally, waste material enters the furnace by dropping through a feed port located in the furnace top. Rabble arms, attached to a centre shaft, rotate to spiral the waste across the face of the hearth to drop holes. The waste drops from hearth to hearth through alternating drop holes located either along the periphery of the hearth or adjacent to the central shaft. Ultimately, the ash falls to the furnace floor. Air and combustion products normally flow countercurrent to the feed waste (from the bottom to the top of the incinerator).

The rabble arms located at each hearth level all rotate in the same direction; additional agitation of the waste (back rabbling) is accomplished by reversing the angles of some of the rabble teeth. Waste retention time is controlled by the design of the rabble tooth pattern and the rotational speed of the central shaft.

Some liquid and gaseous combustible wastes may be injected into the unit through auxiliary burner nozzles.

Waste as it drops through the multiple hearth incinerator is first dried in the upper hearths where some volatile matter may be driven off and due to the lower temperatures in this area may not be properly burned (unless an afterburner section is employed firing suitable fuels). The normal temperatures of the central hearths where combustion takes place is in the order of 900-1000^{o}C. In the lowest hearth, the resulting ash emanating from the combustion hearths is cooled by the upsweep of combustion air from the bottom hearths.

Waste Inputs

Multiple hearth incinerators can be used to dispose of some sludges, tars, and granulated solid wastes. Liquid and gaseous wastes can be used as auxiliary fuel in the burners or injected for incineration depending upon their calorific value and chemical compositions.

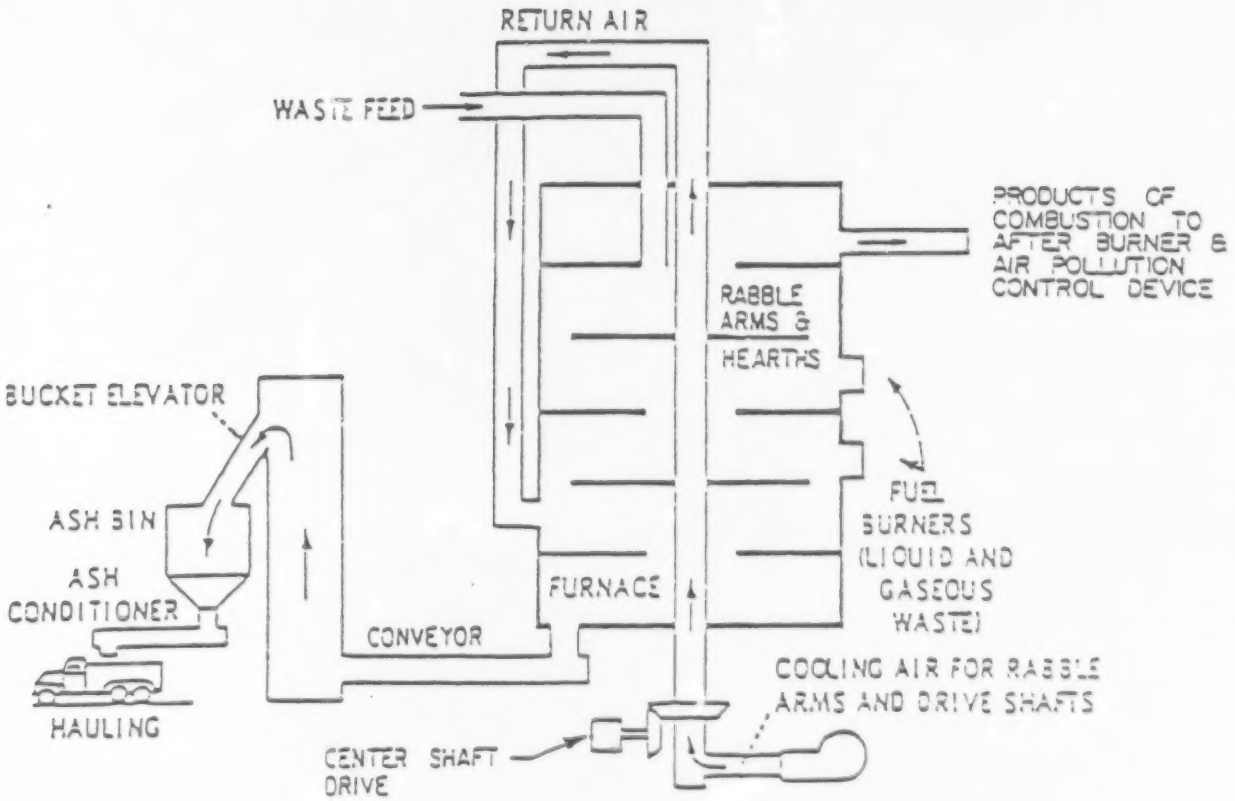


FIGURE 3.4.2 : MULTIPLE HEARTH INCINERATION SYSTEM

Temperatures achieved in combustion hearths are generally not high enough for the destruction of many hazardous wastes (especially chlorinated organics, etc.). Further, available residence time at maximum temperatures is quite short. Appropriate for treatment if the following wastes (by UCD classification): 245; 247-248; 252; 254; 258; 261-264; 281-286; 455; 513; 528; 531-532.

Effluent and Residuals

The multiple hearth incinerator produces two or three effluent waste streams. Liquid and gaseous effluent streams are related to the air pollution control system incorporated to treat air emissions. Wet scrubbing systems may produce a relatively concentrated liquid effluent that requires treatment, or they may incorporate a recirculation and drying feature that eliminates the liquid stream (i.e., contaminants are then removed as dry particulate). The gaseous effluent stream after being treated by the air pollution control system is discharged by means of a stack. The solid inorganic residuals comprise the third effluent stream which are made up primarily of slag particulates and other nonburnables and scrubber dry particulate which require ultimate disposal, generally to a land disposal facility.

Implementation, Reliability

The multiple hearth incinerator has moderate application to waste management. In general, multiple hearths are not suited for wastes containing fusible ash, those which require extremely high combustion temperatures, irregular bulky solids or waste in metal, plastic or similar containers (regardless of size). Multiple hearth incinerators are very susceptible to thermal shock resulting from frequent feed interruptions or large variations of amounts of water in the waste. These conditions can lead to early refractory or rabble arm failures and can make temperature control difficult. When the multiple hearth is applied to thermal oxidation of waste streams, a secondary combustion chamber will be necessary to incinerate unburned contaminants in the combustion gases.

The materials of construction of rabble arms and the central shaft must be suitable for the chemical composition of the waste fed to the unit to resist corrosion effects from reducing atmospheres (i.e., oxygen deficient) that may occur in the combustion zone.' These conditions, in general, arise from the fact that the waste material is ploughed with combustion air passing above the material which may result in a localized reducing atmosphere as the waste material ignites and burns.

Process Applications

Multiple hearth incinerators have been used since the 1930's to incinerate municipal sewage sludge and various similar industrial sludges. In waste management, they have been used to incinerate still bottoms, solid residue from manufacture of aromatic amines, reactor bottoms from PVC manufacture, some chemical sludge, oil refinery sludge, and pharmaceutical waste. They also have been used for carbon regeneration and preparation of similar waste material for reuse.

Economic Factors

Capital costs for a multiple hearth incineration system capable of handling waste streams are high being very dependent upon the type of waste to be burned.

Maintenance requirements are high because of the many internal rabble arms and other portions of the equipment subjected to high temperature combusion conditions. The placing of such metal parts in direct contact with combustion products, especially under reducing atmosphere conditions, has not been evaluated with respect to the shortened operating life and maintenance requirements for such parts.

Operating costs for a multiple hearth incineration system will be highly dependent upon the waste to be burned and the availability of suitable waste gases and liquids of high calorific value that may be required to supplant purchased fuels.

Energy Requirements

Energy requirements are highly dependent on the calorific value of the waste to be destroyed and the availability of waste fuels. Proper management of scheduling will reduce energy requirements to a minimum.

Resource Recovery Potential

Ash discharged from a multiple hearth incinerator usually has a high concentration of metal oxides which may be suitable for recovery of metals, or reuse as an inert material (dependent upon contaminants in the originating waste). Metal recovery or ash reuse can only be effected if the ash is collected on a "batch" type basis so that they may be identified against the actual waste and the original chemical compositions fed to the incinerator. Analysis of the ash would be required in initial reuse applications and related to the original waste materials permitting later large-scale reuse under a controlled management waste incineration schedule.

Environmental Factors

Mulitple hearth incinerator facilities have seen limited use for waste management being very dependent upon the types of waste to be disposed of. In general, they have been employed for the disposal of "low strength" and "low toxicity" sludges and granular material wastes.

The basic combustion process and combustion products path through the multiple hearth incinerator, depending upon the type of waste and its moisture content, may not lend itself to the total combustion of specific chemical compounds or their initial combusion products without the inclusion of a high-temperature afterburner section.

Ash disposal will be to secure landfill sites for ash that is not suitable for reuse; to municipal solid waste landfill sites for inert ash; to metal recovery or reuse in other forms where warranted.

Use of latest technology for flue gas scrubbing would result in minimum liquid waste requiring treatment (or no liquid waste at all) leaving particulate to be disposed of in the same manner as incinerator ash. Emissions to the atmosphere are minimized through the use of proper air pollution control systems, sized and matched to the type and quantity of waste to be handled by the facility.

Regulatory agencies have accepted many multiple hearth incinerators as latest state-of-the-art incineration technology for specific "low toxicity" wastes when coupled with appropriate air pollution control systems.

Pyrolytic Fixed Hearth Incinerator with Secondary Combustion Chamber

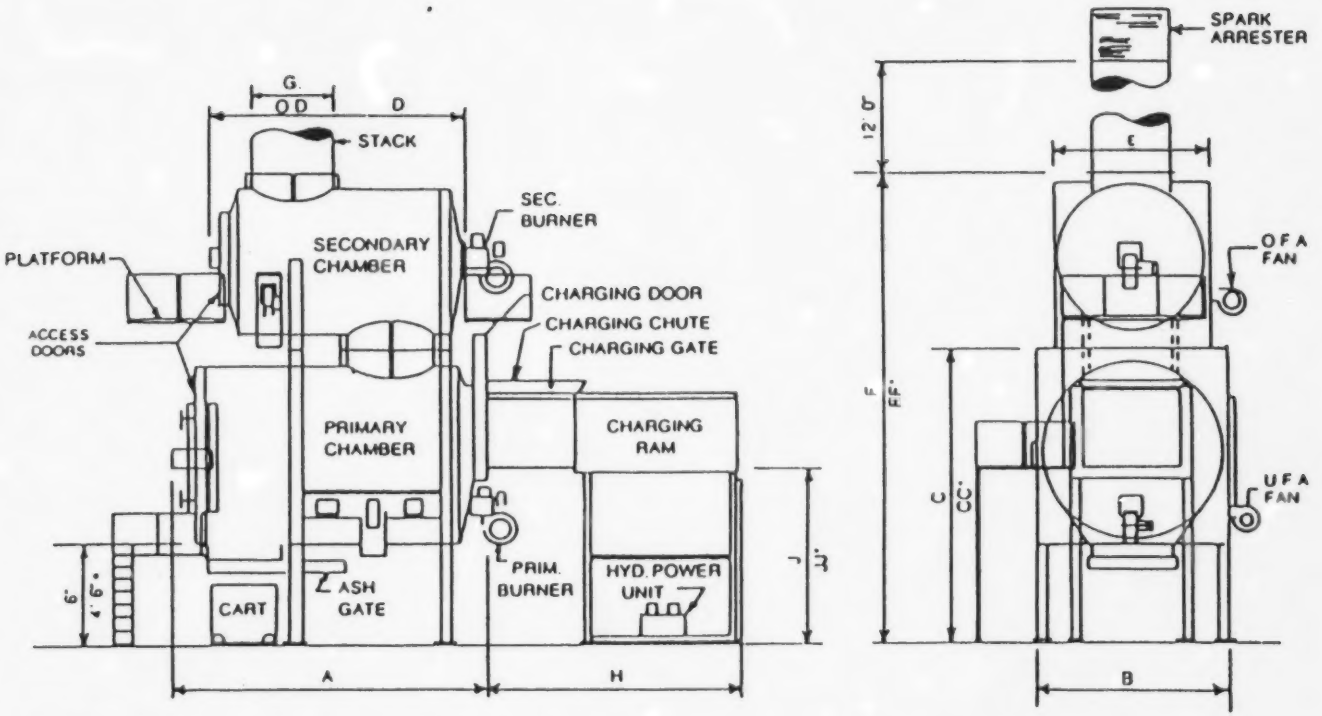
Process Description

Pyrolysis is a technique for decomposing organics at high temperatures with substiochiometric quantities of air followed by burning the volatiles that are driven off in a secondary combustion chamber. In fact, the terms "pyrolytic" and "starved air" combustion are often used interchangeably. For this evaluation, it is assumed they are the same and that pyrolytic or starved air combustion simply means combustion with the amount of primary combustion chamber air controlled to 70% to 80% of stoichiometric so as to promote pyrolytic reactions. Under these conditions, the wastes in the primary combustion chamber do not burn; they are broken down (pyrolyzed) into steam, carbon monoxide and dioxide, volatile vapors and charcoal. Gases formed during pyrolysis contain combsutibles and are burned in the secondary combustion chamber with an excess of oxygen.

A typical configuration for a pyrolytic fixed hearth incinerator is shown in Figure 3.4.11. The incinerator consists of fixed primary and secondary chambers, typically operating at temperatures in the range 650°C to 1100°C, with ancillary feeding equipment for waste solids, sludges, liquids, and drums. Units for handling drums are usually designed to operate batch-wise. The flue gases from the secondary combustion chamber discharge to the energy recovery and flue gas treatment equipment and thence to a stack.

Compared to other incineration methods, the air flow in the primary chamber is low in quantity and low in velocity. The low velocity and near absence of turbulence of the waste results in minimal amounts of particulate carried along in the gas stream. Complete burning can be accomplished in the secondary chamber without additional fuel and the resulting exhaust gas is clean and practically free of smoke and soot.

They may be designed to incorpoate downstream energy recovery.



SOURCE: Morse-Boulger, Inc., Queens, New York.

FIGURE 3.4.11 : PYROLYTIC FIXED HEARTH INCINERATOR.

Waste Inputs

Pyrolytic fixed hearth units are fairly versatile types of incinerator. They operate best on solid feeds but can process liquids, sludges, slurries and drums. The technology has been used for processing some waste from each of the UCD Categories 247, 248, 257, 261, 263, 264, 282, 284, 285, 286, 288, 446, 447, 454, 523 and 531.

Effluent and Residuals

Pyrolysis systems, like other thermal processes, result in the release of a treated flue gas to the atmosphere. A solid (sometimes known as "char") discharges from the primary chamber. It is a form of coke or charcoal suitable for landfilling without prior solidification. However, under upset conditions, it has been known to contain unwanted byproducts and require re-treatment in the incinerator.

Implementation, Reliability

Pyrolytic fixed hearth incinerators are a well-proven technology primarily used for destruction of waste within a plant or complex. They have found limited use in commercial facilities because, in the typical single-train configuration, they can treat a relatively narrow range of wastes.

Process Application

Pyrolytic incinerators are used only on organic-containing wastes. Typical feeds have been wood chips, coke and coke gas from coal, fuel gas, pitch from heavy hydrocarbon still bottoms, petroleum and petrochemial residues, organometallic wastes and oily metal residues.

Economic Factors

Capital costs for pyrolytic fixed hearth incinerators are highly dependent upon the waste quantity and type of waste. Maintenance costs are high on a dollar basis because of the high temperatures in the secondary combustion chambers.

Energy Requirements

Energy requirements are relatively low because the heat for the secondary chamber comes from combustion of the vapors formed in the primary chamber.

Resource Recovery Potential

Residual energy in the hot flue gas products may be recovered in waste heat boilers as steam or electricity.

Environmental Factors

Environmental factors relate specifically to the ash from the primary chamber and the flue gases from the secondary chamber. The ash is a consolidated form of charcoal or "char, which often can be landfilled without prior solidification. Under upset process conditions, particularly low primary chamber temperatures, the char can contain unwanted byproducts and should be recovered and re-treated in the incinerator. Compared to other incineration methods, the air flow in the primary chamber, firing the waste, is low in quantity and low in velocity. The low velocity and near absence of turbulence of the waste results in minimal amounts of particulate carried along in the gas stream. Complete burning is accomplished in the secondary combustion chamber and the resulting exhaust gas is low in particulate matter but contains acid gases that require scrubbers. Because the nature of the process is such that turbulence of the solids in the primary chamber is minimal, materials requiring turbulence for effective combustion, such

as powdered carbon or pulpy wastes may not be completely pyrolyzed in a single pass through the incinerator.

ROCKING KILN

Process Description

The Rocking Kiln Incinerator is a concept developed by Von Roll, Ltt., with one of their goals being to market a unit for handling small tonnages of hazardous waste. It consists of primary and secondary combustion chambers in series similar in shape to those described for the rotary kiln. The primary chamber is a rotatable horizontal cylindrical refractory-lined shell mounted with its axis at a slight slope from the feed to the discharge end. The secondary chamber is a fixed vertical refractory-lined cylinder mounted at the discharge end of the primary chamber. The primary chamber, instead of continuously rotating through 360° as with a rotary kiln, is designed to "rock" through an arc up to 180° only during incineration and discharge.

Solid wastes, sludges, waste drums and liquid wastes can be fed into the kiln. As these wastes move through the kiln, organic matter is burned. Liquid and gaseous wastes and purchased fuels are used as auxiliary fuel in both the primary and secondary chambers. The secondary chamber is used to achieve complete combustion of volatile organics and organics carried by gas-borne particles. Liquid wastes are atomized and burned in suspension.

The primary chamber can be operated under starved air or excess air conditions and in continuous or batch modes. In batch mode, the operator can increase solids retention time significantly to accomplish more complete combustion of material in metal drums. Operating temperatures for the primary and secondary chambers are in the range 800°C to 1200°C.

The largest unit available has a combustion capacity of about 21 GJ per hour (Reference 19) and feed capacity of 2,000 to 2,500 kg/hr. It has been operated on hazardous wastes only at a pilot-plant-scale.

Waste Inputs

The rocking kiln is a versatile type of incinerator. It is capable of handling slurries, sludges, bulk solids of varying sizes, containerized wastes, combustible and non-combustible liquid wastes. The technology is considered suitable for processing of the following wastes (UCD classification): 211-217, 221-223, 241-245, 248, 251, 254, 261-264, 281-289, 446, 454-455, 512-513, 521, 523, 528, 531-532.

Effluent and Residuals

The rocking kiln produces solid inorganic residues which are made up of ash particulates and other non-burnables and which require ultimate disposal, generally to a secure landfill. It also produces a gaseous effluent stream that, after being treated by the flue gas treatment equipment, is discharged through a stack.

Implementation, Reliability

Rocking kilns have not been tested on a commercial scale. The first such units are currently (1987) being started up in Alberta, Canada.

As in other kilns, regularly-scheduled maintenance of kiln refractory (and scrubber systems) is important to the long-term consistent high destruction efficiency of wastes. In addition, the mix of wastes fed to the kiln must be carefully controlled to prevent undesirable chemical reactions in the combustion process that adversely affect slag or ash properties resulting in attack on refractory or deterioration in flue gas treatment efficiency. The rocking action of the kiln would tend to minimize damage to the refractory from the passage of metal drums through the unit.

Process Application

It is ancticipated that the rocking kiln will find applications in the incineration of small quantities of hazardous organic wastes and as an auxiliary unit for handling metal drums.

Economic Factors

Capital costs for a rocking kiln are highly dependent upon the waste quantity and type of feed.

Maintenance costs are high because the units operate under severe high temperature conditions. However, mechanical damage to refractory from metal drums will be minimized due to the rocking action which does not cause the drums to drop on the refractory lining.

Energy Requirements

These are highly dependent upon the calorific value of the wastes to be destroyed. Proper management of scheduling will minimize energy costs.

Resource Recovery Potential

Residual energy in the hot flue gas may be recovered in a waste heat boiler as preheated combustion air, steam or electricity.

Environmental Factors

The environmental factors relate to the ash from the destroyed waste and the flue gases from the combustion. In the non-slagging mode of operation, the ash is an unconsolidated material that may require solidification before disposal in a secure landfill. The rocking action of the primary chamber is such that agitation of the solid waste and turbulent contact with the combustion gases is minimized. Therefore, materials requiring turbulence for effective combustion such as powdered

carbon and pulpy wastes would not be appropriate candidates for incineration in this unit.

The flue gases require treatment to remove particulates, acid gases, metals and unburned organics. The low turbulence of the solid waste should result in low carryover of particulate matter.

APPENDIX B

REASONS WHY CERTAIN INCINERATOR TECHNOLOGIES DID NOT PASS THE "PROVEN TECHNOLOGY" SCREEN

APPENDIX B
REASONS WHY CERTAIN INCINERATOR TECHNOLOGIES
DID NOT PASS THE "PROVEN TECHNOLOGY" SCREEN*

Technology Not Passed	Reason for Not Passing
Multiple Hearth	Multiple hearth furnaces widely used for sewage sludge drying and metallurgical ore processing at feed rates adequate for OWMC requirements. However, no documented examples of multiple hearths incinerating hazardous wastes at 99.99% DRE.
Calciner/Cement Kiln	Several commercial installations incinerate hazardous wastes at 99.99% DRE. However, all such installations accept only liquid wastes with no more than traces of ash, and due to product purity requirements are unable to process hazardous waste sludges or solids of the types produced in Ontario. Moreover, the hazardous wastes can only constitute a small fraction of the total fuel because of the unsophisticated flue gas treatment equipment which does not include acid gas removal capabilities.
Plasma Arc/Microwave Plasma	Has been operated at pilot-plant-scale only and only on hazardous liquid feeds. No 12-month commercial applications.
Molten Salt Incinerator	Has been operated with hazardous solid, sludge and liquid feeds on demonstration runs only. No 12-month commercial application.
Rocking Kiln	Has been operated with hazardous solid, sludge and liquid feeds at pilot-plant-scale only. No 12-month commercial applications.

*A "proven technology" has been commercially demonstrated to perform reliably for a period of at least 12 months, on a scale and in a manner comparable to that required by the OWMC facility.

APPENDIX C

REASONS FOR DELETING FACTORS

APPENDIX C
REASONS FOR DELETING FACTORS

Factor Deleted	Reason for Deleting
1. Air emissions under normal operating conditions - from fugitive emissions	"Fugitive emissions" in the incineration area have been defined in previous studies (Reference 15) as originating in the incinerator feed storage and handling area. The feed storage and handling is the same for every incinerator technology.
2. Air emissions under normal operating conditions - from variations in amount of flue gases among technologies	Variation in amounts of flue gases is not significant. Average amounts for the revised cases are: Fluidized Bed - 23000 scfm Rotary Kiln - 23000 scfm Liquid Injection - 23000 scfm Pyrolytic Fixed Hearth - 21000 scfm
3. Air emissions under abnormal operating conditions - from accidental releases	"Accidental releases" in the incineration area have been defined in previous studies (Reference 15) as most likely to occur in the incinerator feed storage and handling area. The feed storage and handling is the same for each incinerator technology.
- from variations in quality of flue gas among technologies	In previous studies (Reference 15), the source of release of flue gases under abnormal operating conditions has been identified as a "scrubber failure" and the chemicals of concern as "acid gases". The amounts of acid gases in the flue gas are determined primarily by the acid gas constituents in the waste feed. The feeds are the same for each technology and so, by these definitions, there should be no variation in quality among technologies.

APPENDIX C--Continued
REASONS FOR DELETING FACTORS

Factor Deleted	Reason for Deleting
6. Groundwater contamination under abnormal operating conditions - due to leakage of hazardous materials into groundwater	
- from accidental spills of hazardous materials	Spills originate in incinerator feed handling and storage area which is the same for every technology.
7. Direct exposure due to accidents along access routes	Accidents along access routes are associated with transportation of wastes and chemicals. The same amounts and types are transported by the same means for each technology.
8. Occupational health and safety, exposure of workers during normal operations.	
- from leakage from operating equipment	Major sources of leaks are from types of equipment in feed handling and storage area which is same for every technology. Examples are tank vents, pump glands and seals, solids conveyors.
- from dust generation	In all the technologies, during normal operation dust generation is mitigated by enclosures and ventilation. Therefore, under normal conditions, there is no dust released to atmosphere from the incineration area.
- during maintenance of equipment	Risks related to maintenance of equipment are associated with possible exposure to any or all types of OWMC hazardous wastes. These risks are mitigated by proper cleanout procedures and by workers wearing personal protective equipment when doing maintenance work. Therefore, the type of risk is approximately the same for each technology.

APPENDIX C--Continued
REASONS FOR DELETING FACTORS

Factor Deleted	Reason for Deleting
9. Occupational health and safety, exposure of workers during abnormal operations - from accidental leakage due to equipment failure or operator error.	Equipment most prone to leakage due to equipment failure is in feed storage and handling area which is same for all technologies. Examples are fire in storage tank, storage tank overflow, pipe flange leak.
10. Impacts, natural	All incinerator technologies require approximately the same land area; therefore disruption and displacement of features will be the same for each. Incineration to eliminate the hazards of hazardous waste is in support of government policies and plans.
11. Impacts, social - displacement of residents and community features	Same land area required for each technology. Therefore, displacement the same for each.
12. Impacts, social - disruption of adjacent existing residents and community features	
- due to noise	Major noise-producting equipment not in incinerator. Examples are induced draft fans, tank agitators, compressed air pumps. Therefore, this indicator not applicable.
- due to visual	Highest piece of incinerator equipment is secondary combustion chamber, which each technology has.
- due to odors	Main odor releases occur when opening shipping containers and when transferring wastes from containers to storage. Amount of such waste handling is same for each technology.

APPENDIX C--Continued
REASONS FOR DELETING FACTORS

Factor Deleted	Reason for Deleting
- due to dust	No dust releases expected during normal operation due to mitigation by enclosures and ventilation. Dust releases during abnormal operation would not be expected to leave property due to buffer zone. Therefore, no social impact.
13. Impacts, social - disruption of adjacent future residents and community features	Same for each technology as described in 12 above.
- disruption of residents and community features along access roads	Same materials transported on access roads for each technology.
- conflict with government policies and plans	Each technology accomplishes same purpose with same social impact. Therefore, conflicts with government policies and plans are same for each technology.
14. Impacts, economic	No special municipal services required by any incinerator technology. Number of employees approximately the same for each technology.
15. Impacts, land use	Land area required for each incinerator approximately the same. Therefore impacts the same.
16. Impacts, agricultural resources	Land area required approximately the same for each incinerator technology. Therefore, displacement and disruption of resources the same for each.

APPENDIX C--Continued
REASONS FOR DELETING FACTORS

Factor Deleted	Reason for Deleting
17. Operations - complexity	The waste feed storage and handling operations are complex but are the same for each incinerator technology since each will be processing the same wastes. Best available technology includes automatic control of incinerator operations using computers. Therefore, this part of the operation is no longer complex (from an operations viewpoint). Consequently, the complexity of operations is very similar for each incinerator technology.

APPENDIX D

COST DATA

APPENDIX D

COST DATA

BASIC CAPITAL COST DATA

Capital costs for rotary kiln/SCC incinerators were based on cost estimates supplied by OWMC, originally prepared in 1984 by Environmental Elements in Canadian dollars. Their original data is shown in Table D.1.

That data was based on a kiln/SCC feed capacity of 30,000 tonnes/yr (4760 kg/hr). In order to scale the costs to other incinerator sizes in 1987, a scaling factor of 0.6 was used (as suggested by Environmental Elements). Equipment price indexes for 1984 and 1987 are almost equal and these cost estimates are factored from bare equipment costs; so no inflation factor was used.

CAPITAL COST FOR ROTARY KILN/SECONDARY COMBUSTION CHAMBER

Based on the data in Table D.1, the capital cost in Canadian dollars for the incinerator composed of a rotary kiln and secondary combustion chamber with a design feed capacity of 4760 kg/hr equivalent to 66.6 GJoules/hr is as follows:

Rotary kiln refractory	Canadian $	517,269
Shell		480,088
SCC Refractory		259,750
SCC Shell		348,247
Burners (2)		32,000
Waste burners (3)		191,504
Solid feed		540,000
Custom waste		120,000
Front wall		485,000
Drum system		200,000
Ash handling		199,098
Subtotal, Bare Equipment Cost		$3,372,956

TABLE D.1
CAPITAL COSTS OF VARIOUS SIZES OF INCINERATORS

Von Roll Type	5
Description (%)	OWMC
MMBTU/Hr Capacity	73.9
GJoules/Hr Capacity	
MMBTU/Hr Design	62.9
GJoules/Hr Design	66.6
Feed KG/Hr	4760
LHV	14000.0
Drum Dia M	4.0
Ft	13.1
Length M	11.0
Ft	36.1
GJ/M2	5.299
GJ/M3	0.482
Combustion Temp F	1230.0
Flue Gas KGMOL/Hr	1519.6
Flue Gas MM M3/Hr	0.1169
SCC retention secs	2.5
SCC vol M3	81.20
SCC vol Ft3	2866
Flue gas lb mol/hr (Prim)	3349
Flue gas lb mol/hr (Sec)	4547
Flue gas lb mol/hr (Tert)	5964
Flue gas lb mol/hr (Stack)	7068
COST CALCULATION SCF 1984	
Equipment	
Rot Kiln 9in Refractory $38.20/in.sq.ft.	517269
Rot Kiln Shell $283.50/sq.ft.	480088
SCC Refractory	259750
SCC Shell	348247
Fuel Burners 2 @ $16000	32000
Waste Burners 3 x 50%	191504
Solid feed system (Von Roll)	540000
Custom waste system	120000
Front wall assembly	485000
Drum system	200000
Ash Handling	199098
Waste heat Boiler	927774
Pollution Control	1250488
Blower	48953
Stack with 50 ft. breaching	41581
TOTAL EQUIPMENT	5641751
Installation 50%	2820876
Instrumentation 20%	1128350
Subtotal	9590977

TABLE D.1--Continued
CAPITAL COSTS OF VARIOUS SIZES OF INCINERATORS

EPCM costs	1438647
Contingency 20%	2205925
TOTAL	13235548

Installation @ 50%	$1,686,478
Instrumentation @ 20%	674,591
Subtotal	$5,734,025
EPCM @ 15%	$ 860,104
Contingency @ 20%	1,146,805
Total Capital Cost	$7,740,934
	say, $8,000,000

ROTARY KILN/SCC MAINTENANCE COST

The maintenance cost estimate was based on factors supplied to OWMC by Environmental Elements which gave maintenance costs as a percentage per year of the capital cost of the equipment. The factors were as follows:

Rotary kiln refractory	100% per year
Rotary kiln shell	4%
SCC refractory	20%
SCC Shell	4%
Fuel burners (2)	9%
Waste burners (3)	9%
Solid feed	9%
Custom waste	9%
Front wall	4%
Drum system	9%
Ash handling	9%

For the kiln/SCC incinerator equipment with design feed capacity of 30,000 tonnes/yr (4760 kg/hr) the estimated maintenance cost is $737,187. This is equivalent to 9.2% of capital cost (based on $8,000,000) or $25/tonne (based on 30,000 tonnes/yr).

FLUIDIZED BED INCINERATOR COSTS

Assume that the capital cost of a fluidized be incinerator is the same as the capital cot of a rotary kiln of equal capacity. In order to estimate the capacity of the fluidized bed incinerator alternative, the following distribution of feeds between the fluidized bed and the parallel rotary kiln was used:

Fluidized Bed		Rotary Kiln	
Liquid	870 tonnes/yr	Bulk Solids	7,860 tonnes/yr
Liquid and Sludges	11,070	Solids and Sludges	5,100
Solids and Sludges	5,100		
Subtotal	17,040		12,960

Fluidized bed capital cost: $(17{,}040 / 30{,}000)^{0.6}$ ($8,000,000) = $\$4.83 \times 10^6$

Rotary kiln/SCC capital cost: $(12{,}960 / 30{,}000)^{0.6}$ ($8,000,000) = $\$5.70 \times 10^6$

Total Capital Cost $\$10.5 \times 10^6$

Maintenance cost: $\frac{0.092\ (\$10.5 \times 10^6)}{30{,}000} = \$32/\text{tonne}$

LIQUID INJECTION INCINERATOR COSTS

Assume that the parallel rotary kiln is sized to accept 30,000 tonnes/yr of waste based on the heat balance of average wastes. Such sizing is considered necessary because, for certain combinations of waste, all the heat in the liquid wastes will be needed in the rotary kiln in order to maintain kiln temperature when feeding low-btu solids and sludges. Assume that the liquid incinerator costs 25% as much as a rotary kiln and that the required capacity of the liquid injection incinerator is estimated as follows:

Liquid Injection		Rotary Kiln	
Liquids	870 tonnes/yr	Bulk solids	7,860
Liquid and Sludges	11,070	Solids and Sludges	10,200
Subtotal	11,940		18,060

Liquid incinerator capital cost: $(0.25)\ (11{,}940 / 30{,}000)^{0.6}$

($8,000,000) = $\$1.2 \times 10^6$

Rotary kiln/SCC incinerator capital cost: $\$8.0 \times 10^6$

Total capital cost: $\$9.2 \times 10^6$

Maintenance cost: $\frac{0.092\ (9.2 \times 10^6)}{30{,}000} = \$28/\text{tonne}$

PYROLYTIC FIXED HEARTH INCINERATOR CAPITAL COSTS

In order to estimate these costs, it was assumed that 50% of the waste (15,000 tonnes/yr) is fed to each unit and that pyrolytic units cost 70% as much as rotary kilns.

Pyrolytic fixed hearth capital cost:

$$(15{,}000 / 30{,}000)^{0.6} \quad (2)\ (0.7)\ (8{,}000{,}000) = \$7.4 \times 10^6$$

Maintenance cost: $\dfrac{0.092\ (\$7.4 \times 10^6)}{30{,}000} = \$23/\text{tonne}$